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THE BEDROCK GEOLOGY

OF THE

BATH AND PORTLAND 2° MAP SHEETS, MAINE

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CONTENTS

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INTRODUCTION

This report presents a description of the geology of the Bath and Portland 2^{o} map sheets (scale 1:250,000) in Maine (Figure 1). Also included is a discussion of the geology of the Rochester-Northwood-Epping area of New Hampshire in which I have carried on reconnaissance investigations.

The map is located on the southeast flank of the Kearsarge-Central Maine Synclinorium of Lyons, et al. (1982), and straddles the Rye Anticline of Billings (1956) and the complexly folded and faulted Casco Bay Synclinorium, a klippe of Acadian age (Figure 2). The stratigraphic sequence includes the Rye and Cross River Formations of probable Precambrian age, the Casco Bay Group of possible Precambrian to Ordovician age, the Merrimack Group of possible Precambrian to Silurian age, the Shapleigh Group of Silurian and/or Devonian age, the Central Maine Sequence of late Ordovician to Silurian age, the Benner Hill Sequence of late Ordovician age, and the Bucksport Formation of Ordovician or Silurian age. These rocks were extensively folded, metamorphosed, and intruded by calc-alkaline granitic rocks and pegmatites during and slightly after the Acadian Orogeny of late early Devonian time. The Casco Bay Group, Cross River Formation, Rye Formation, and possibly the Merrimack Group may also have been deformed and metamorphosed during a late Precambrian or very early Paleozoic orogeny. Major faulting includes folded premetamorphic faults related to early phases of the Acadian Orogeny, and a variety of strike-slip and normal faults of the Norumbega Fault System with movement dating from late stages of the Acadian Orogeny on into the Mesozoic. Post orogenic igneous activity in the Mesozoic resulted in the emplacement of alkalic stocks and ring complexes of the White Mountain Magma Series, basic dike swarms, and small basic intrusive complexes with associated surface volcanic rocks and explosion breccias.

The reader should accept this study as a state-of-the-art discussion about the geology of southwestern Maine as it is understood at the time of the writing. In this time of very rapid development of concepts and accelerated field mapping, not only in this map area but in adjacent areas, our understanding of the geology will constantly change and revisions will have to be made.

In this report place names in New Hampshire will be so noted. Place names without state designation will always refer to geographical locations in Maine.

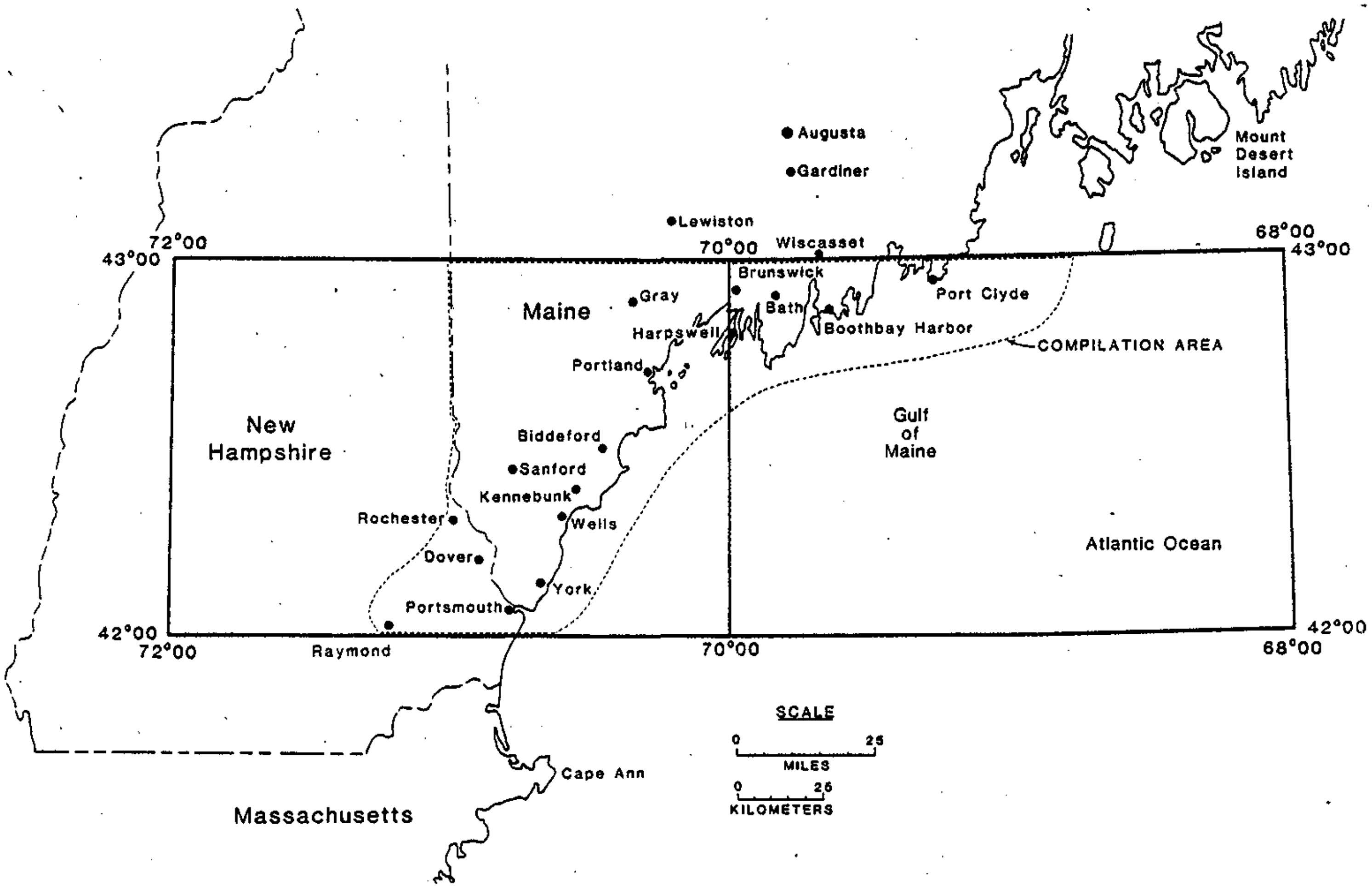

Figure 1. Location of the Bath and Portland 1 X 2° sheets, Maine.

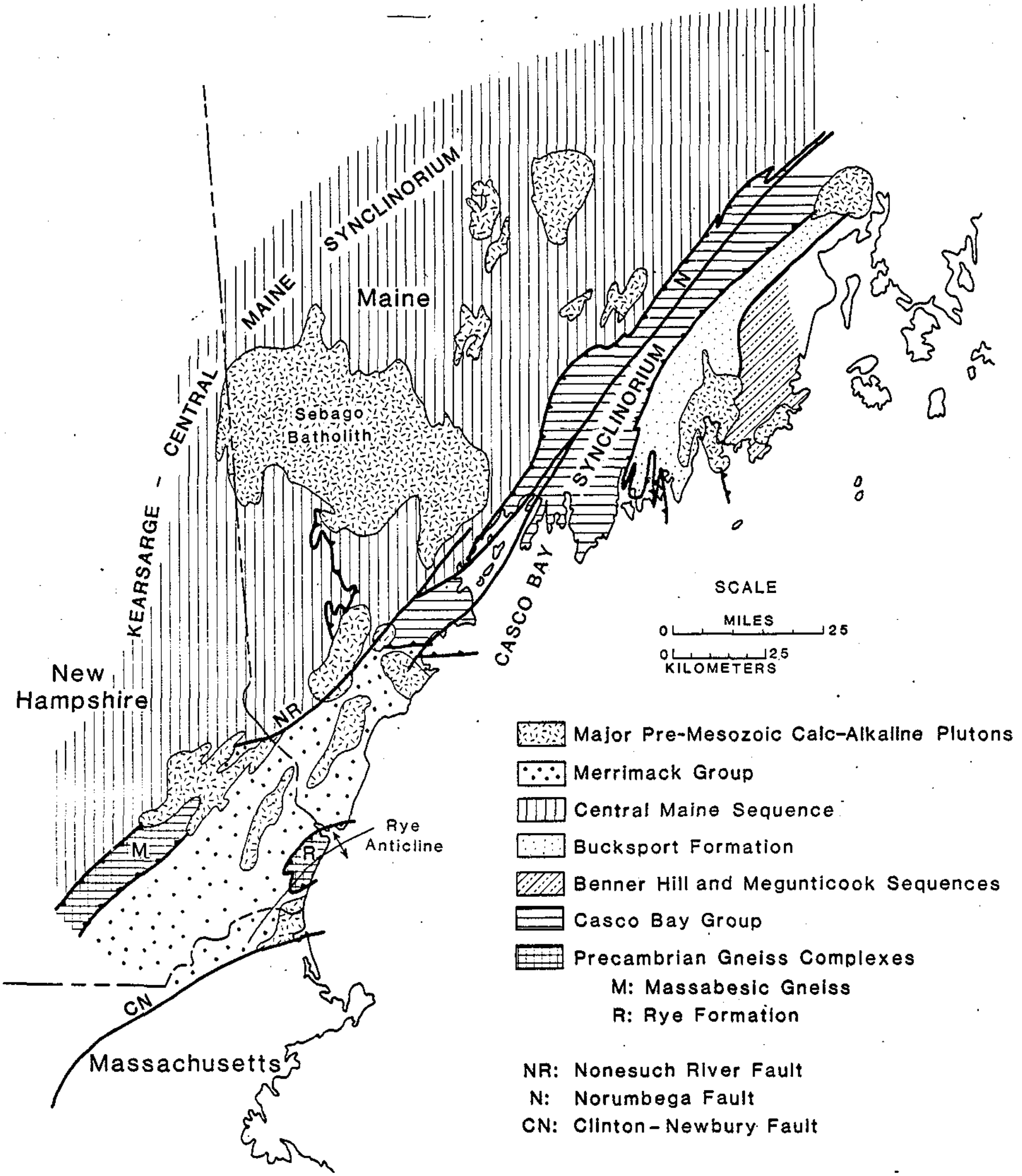

Figure 2. Generalized geologic map of Southwestern Maine and adjacent area.

DESCRIPTION OF STRATIGRAPHIC UNITS

This section includes for each stratigraphic unit a discussion of its name, reference or type locality, distribution, lithology, thickness, the nature of contacts, and relations to overlying and underlying units. Correlations and ages are discussed in a separate section at the end of the description of all units. Estimated modes of lithologies of many of the rock units are given in Appendix I.

Previous Investigations

C. T. Jackson (1837, 1838, 1839) and C. H. Hitchcock (1861, 1862) made brief references to the geology of the region, but their observations and interpretations were so generalized as to be of little help in understanding the stratigraphy and structure of the area. F. J. Katz (1917) conducted the first significant investigation of the region, mapping, describing, and naming the major stratigraphic units of the area. Most of the formational names used in this report were defined by Katz, and survive with only minor changes, mostly in the substitution of the word "Formation" in place of Katz's lithologic designations. Recent detailed mapping sponsored by the Maine Geological Survey by Bodine (1965), Gilman (1965, 1970, 1977) and Hussey (1962, 1968, 1971a, 1971b, work in progress) has produced a refinement of the stratigraphic units, including the mapping of significant members, and a clearer understanding of the ages of the stratigraphic units and of the structure of the area.

Rye Formation

Name. Wandke (1922) proposed the name "Rye Gneiss" for rocks typically exposed at Rye Beach in southeastern New Hampshire. Billings (1956) suggested that the name be changed to Rye Formation, and this usage is followed in this report. Katz (1917) originally referred to these rocks as the "Algonkian Complex".

Distribution. The Rye Formation is exposed in a belt approximately 9 km wide and 33 km long from Gerrish Island in Kittery, Maine, southwest along the coast of New Hampshire to Hampton Falls, New Hampshire. Between Hampton Falls and Seabrook, New Hampshire, it ends in the nose of a southwest-plunging antiform (Novotny, 1969). The Formation is also exposed on the Isles of Shoals 8 km offshore from Portsmouth, New Hampshire (Fowler-Billings, 1959).

Lithology. Billings (1956) divided the Rye Formation into two members, an upper metavolcanic member and a lower metasedimentary member. The writer (Hussey, 1962) originally interpreted the entire sequence exposed on Gerrish Island to be part of the upper metavolcanic member, but later recognized the metasedimentary member in a northeast-plunging antiform at the very southern tip of Gerrish Island (Hussey and Pankiwskyj, 1976). Recent remapping (Hussey, 1980) suggests that all of the Rye Formation on Gerrish Island is of metasedimentary origin and that all of the feldspathic lithologies originally interpreted as volcanic parts of the sedimentary pile are, instead, migmatite stringers and injected sills.

The major lithologic unit of the Rye Formation on Gerrish Island is an association of fine-grained mylonitized dark chocolate-brown metapelite with biotite, muscovite, garnet, quartz, plagioclase, fibrolitic sillimanite, relict staurolite, and, occasionally, relict andalusite; mylonitized fine-grained 1 to 2 cm alternations of chocolate-brown quartz-plagioclase-biotite gneiss and medium greenish-gray quartz-plagioclase-hornblende-biotite gneiss; and mylonitized medium gray fine to medium-grained quartz-plagioclase-biotite gneiss. Partially crushed and rolled porphyroclasts of plagioclase and potash feldspar up to 4 cm in longest dimension are locally abundant, giving these metasediments a characteristic blastomylonitic fabric. These rocks, in particular the metapelites, are heavily migmatized and injected by sills of medium- to coarse-grained granite to granodiorite gneiss having a protomylonite to blastomylonite fabric, and ranging in thickness from 1 cm to several meters. It is the regularity of these feldspathic layers that led earlier investigators (including the writer) to interpret them as pyroclastic volcanic interbeds, and because of their abundance to conclude that the association is principally of volcanic origin. Close examination reveals that these feldspathic layers commonly cross-cut relict bedding at very slight angles and therefore must be injected, not interbedded, material.

Within this lithic association are several thin units: dark gray amphibolite with calc-silicate laminae occurring as two belts approximately 25 m thick along the southern and western shores of the Island; rusty-weathering black sulfidic and graphitic schist approximately 15 m thick; impure marble approximately 10 m thick; and flinty-textured, finely and evenly pin-striped chalky-weathering dark chocolate-brown ultramylonite with occasional pseudotachylite veinlets. The ultramylonite forms a zone between the Kittery and Rye Formations and a 30 to 50 m wide zone at the southern tip of the Island, plus several narrower zones throughout the Island. These ultramylonites are interpreted to be ductile fault zones. The ultramylonites, as well as all other rocks of the Rye Formation are cut by numerous basic dikes of presumed Triassic or younger age.

Pegmatite sills and irregular stringers are common and cut all rock types except the ultramylonites and basic dikes. These pegmatites have a non-exotic mineralogy of microcline, albite, quartz, muscovite, biotite, and occasionally black tourmaline. These rocks have a protomylonitic fabric.

From this latest investigation the writer (Hussey, 1980) concludes that no part of the Rye Formation on Gerrish Island is of felsic volcanic origin, the protoliths being, instead, pelite, calcareous siltstone, sandstone, marble, and carbonaceous shale. The amphibolite, with abundant calc-silicate laminae may represent metamorphosed dolomitic muds rather than basic volcanics. Felsic blastomylonitic gneiss bands are injected material rather than volcanic interbeds.

Thickness. The thickness of the Rye Formation is difficult to estimate because of the amount of repetition due to minor folding, and the uncertainty of whether felsic gneisses represent metasomatic replacements within the metasediments or whether they are magmatic injections that dilated the metasedimentary host. A further complicating factor is that Mesozoic basic dikes have dilated the outcrop belt of the Rye Formation considerably. With these uncertainties in mind the writer suggests that the thickness of the Rye Formation exposed on Gerrish Island may be on the order of 200 to 300 m.

Contacts. The contact between the Rye and Kittery Formations is the northern of the two principal ultramylonite belts described above and is thus interpreted to be either a thrust or strike-slip fault contact.

Cross River Formation (new name)

Name and Reference Locality. The Cross River Formation is named for exposures centered around Cross River, a land-locked tidal bay in Boothbay. The reference locality for the Formation is the shoreline exposure on the northern third of the west shore of Cross River in the Dover district of Boothbay.

Distribution. The Cross River Formation crops out in two separate belts: 1) a 7.5 km long, 2 km wide lenticular belt in the center of the Boothbay Antiform between Boothbay Center and Edgecomb, and 2) a 12 km long, ~~4~~ km wide belt between Bristol Mills and the west side of Pemaquid Point in the town of Bristol. The latter belt, mapped to date only in the Boothbay 15' quadrangle, trends northwesterly into the Louds Island 1:24,000 quadrangle where its distribution is as yet unknown.

Lithology. In the Boothbay area, the Cross River Formation consists of two mapped but unnamed members (Hussey, work in progress). The upper member consists of non-rusty thin bedded to massive, fine-grained medium gray quartz-placioclase-biotite±garnet granofels, medium but irregularly textured medium dark gray non-rusty quartz-plagioclase-biotite-garnet gneiss with garnets up to 1 cm, and dark gray medium to coarse grained amphibolite. This unit is absent in the Bristol belt.

The lower member, present in both belts, is a heterogeneous assemblage of very rusty to very slightly rusty-weathering medium to coarse grained migmatitic gneiss with feldspar poprhyroblasts up to 2 cm, and abundant tabular blocks of non-rusty medium gray quartz-plagioclase-biotite granofels. These blocks range in longer dimension from 10 cm to 5 m or so, and have an orientation generally parallel to the foliation of the gneiss. Sillimanite and graphite are locally abundant in the migmatitic gneiss. This gneiss locally grades into very rusty migmatized quartz-feldspar-biotite-sillimanite-graphite schist with interbeds of rusty quartz-plagioclase-biotite-graphite±sillimanite granofels. The non-rusty granofels blocks in the rusty gneiss probably represent lithologies interbedded with the rusty schist that, because of composition, were not migmatized but were pulled apart when the migmatite was very plastic and mobile.

Contacts. The Cross River Formation is overlain by the Bucksport Formation. Because of the greater degree of deformation of the rocks of the Cross River Formation as compared with the Bucksport Formation, the contact may possibly be an angular unconformity. Alternatively, it may be a premetamorphic folded fault. No units are known beneath the Cross River Formation.

Thickness. The upper member is approximately 75-100 m thick based on the mapped width of outcrop on the northeast part of the Boothbay belt. The thickness of the exposed portion of the lower member is difficult to estimate but probably does not exceed 500 m. A maximum thickness cannot be stated because no units are known to lie beneath the Cross River.

CASCO BAY GROUP

Introduction

The Casco Bay Group was named and first described by Katz (1917). In the Group he included the Cape Elizabeth Slate, Spring Point Greenstone, Diamond Island Slate, Scarboro Phyllite, Spurwink Limestone, Jewell Phyllite, and Macworth Slate. Bodine (1965) recognized the same units in the Group, but changed the lithologic designations to the generalized term "Formation" with the exception of the Spurwink Limestone, a name that he retained unchanged from Katz's nomenclature. Hussey (1965, 1968, 1971a, 1971b, work in progress) has followed Bodine's terminology, but has included the Cushing Formation in the Casco Bay Group. Katz (1917) originally regarded the Cushing lithology as a fine-grained porphyritic gneissoid granodiorite, but mapping by Hussey and Bodine has clearly shown that these rocks include felsic and basic metavolcanics and a variety of metasediments, and that none are likely to represent a deformed granodiorite intrusive.

Cushing Formation

General Statement. The rocks of the Cushing Formation lie in part unconformably, and in part conformably beneath the Cape Elizabeth Formation (Hussey, 1981, p. 38). The Cushing shows strong changes across the strike belt in the Casco Bay area, but changes along strike are much more gradual. Across strike the Cape Elizabeth lies upon different lithologies of the Cushing sequence at nearly all exposed contacts, whereas parallel to strike, the Cape Elizabeth rests upon the same lithology of the Cushing for distances up to several tens of kilometers. Similar variations are true of minor units within the Cushing assemblage -- short distance changes across strike and relative persistence along strike. In part, these changes may be due to lateral sedimentary facies variations across strike, and, if the Cushing Formation was tilted and eroded before the Cape Elizabeth Formation was deposited, may reflect lithic variations of the Cushing metavolcanic/metasedimentary pile.

Name and Reference Locality. The Cushing Formation is named from exposures on Cushing Island in Casco Bay. In the discussion that follows formal member names are proposed for subdivisions of the Cushing, and, accordingly, reference localities are designated for each member, not for the formation as a whole.

Distribution. The Cushing Formation is exposed in three principal belts:

1) The South Portland-Harpswell belt, averaging 3 km in width extending from South Portland through the major islands (Cushing, Peaks, Long, southeastern tip of Great Chebeague) to Harpswell where it adjoins belt 2 across the Flying Point Fault (one of the principal fault traces within the Norumbega Fault Zone).

2) The Falmouth-Brunswick belt, extending from Falmouth Foreside northward through Freeport and Brunswick ultimately to the Bangor area well to the north of the discussion area. This belt has a maximum width of approximately 14 km in the Gardiner area just north of the discussion area, and narrows steadily southward, pinching out against the Flying Point Fault.

3) The East Harpswell-Merrymeeting Bay belt, 3 km wide and 24 km long, extending from the southern end of East Harpswell north to Merrymeeting Bay in Topsham where it is separated from the first belt by the Cape Elizabeth Fault, another of the traces of the Norumbega Fault Zone.

A fourth belt in the Wiscasset 15' quadrangle and extending into the Boothbay 15' quadrangle of this report area was mapped by Hatheway (1969) as the Edgecomb Gneiss which he correlated with the Cushing Formation. From detailed mapping in progress in the Boothbay quadrangle, the writer feels that the Edgecomb Gneiss may represent a syntectonic felsic intrusive and therefore not a part of the Cushing Formation.

Subdivision of the Cushing Formation

General Statement. The Cushing Formation is a sequence of quartzo-feldspathic gneisses representing felsic to intermediate metavolcanics and feldspathic volcanogenic metasediments, and minor calc-silicate, amphibolite, metapelite, and sulfidic gneiss and schist. Within each of the above-noted parallel strike belts, members of the Cushing Formation have been mapped and are hereby proposed as formal subdivision of the Formation. In general, few of these members can be lithically correlated with certainty from one belt to another. Estimated modes for representative lithologies of these members are given in Appendix I.

South Portland-Harpswell Belt

The Cushing Formation in the South Portland-Harpswell belt is subdivided into the Wilson Cove, Peaks Island, and Bustins Island Members.

Wilson Cove Member

Name and Reference Locality. The Wilson Cove Member is named from extensive exposures of the Member at Wilson Cove on the west shore of Harpswell Neck, Harpswell, Maine. The type locality for the member is the small unnamed point 0.3 km east of Simpson Point in the Pennellville area of Brunswick. Here, the entire thickness of the Member is exposed.

Distribution. The Wilson Cove Member is restricted to the eastern edge of the South Portland-Harpswell belt, corresponding to the east flank of the Cushing Antiform. It is also present in the core of the Spurwink Hill Antiform in Cape Elizabeth, and on the west limb of the Prouts Neck Synform in Scarboro (Hussey, 1971a). Pankiwskyj (1978) has mapped rocks essentially identical to the Wilson Cove in the Liberty area about 60 km north of the map area.

Lithology. The Wilson Cove Member consists of a distinctive sequence of generally garnet-rich non-rusty and very rusty-weathering dark gray to black thin-bedded to massive rocks that include the following lithologies (Hussey 1971a, 1971b): 1) Garnet-quartz-plagioclase-biotite schist; 2) coarse-grained garnet-biotite schist; 3) biotite-garnet-plagioclase-quartzite; 4) garnet-cummingtonite-hornblende-biotite-quartz-plagioclase-gneiss and amphibolite; and 5) biotite-muscovite schist. The garnet present in these rocks is manganese-rich spessartite. Occasional secondary films of pink rhodochrosite have been noted on freshly exposed joint and fracture surfaces, another indication of the manganese-rich character of these rocks. The above noted lithologies are associated in a random non-systematic manner, and thus do not reflect any stratigraphic succession with the exception that, in the type area, the rusty mica schist forms the uppermost part of the Member.

Contacts. At the type area in Pennellville, the contact with the overlying Cape Elizabeth Formation is not clearly exposed but appears to be conformable (structural attitudes seem to be parallel in both units, and degree of deformation and metamorphism appear to be the same). However, 2 km to the north of the type locality, the Wilson Cove is cut out along the Cushing-Cape Elizabeth contact. The significance of this disappearance is discussed in a subsequent section.

The contact with the underlying Peaks Island Member is conformable. In places, notably in the Lookout Point area of Harpswell Neck, Wilson Cove lithologies occur as narrow bands 5 to 30 m thick within light gray quartzo-feldspathic gneiss of the Peaks Island Member, suggesting local facies intertonguing with that Member. At Prouts Neck, Scarborough, approximately 25 m of Peaks Island lithology separates Wilson Cove rocks from the Cape Elizabeth Formation. Along the east flank of the Cushing Antiform between Chimney Rock, Cape Elizabeth, and Whaleboat Island, Harpswell, the member is missing.

Thickness. At the type locality the Wilson Cover Member is approximately 120 m thick, whereas at some localities, such as Chimney Rock in Cape Elizabeth, the member is absent, probably due to nondeposition. The thickness of the Member thus varies from 0 to 120 m.

Peaks Island Member (new name)

Name and Reference Locality. The Peaks Island Member is named from shoreline exposures on the eastern two thirds of Peaks Island in Casco Bay. These exposure are designated as the reference locality for the Member. Equally superb exposures occur along the shores of Cushing, Long, Cliff, and parts of Great Chebeague Islands.

Distribution. The Peaks Island Member occupies most of the area of the South Portland Harpswell belt in the core of the Cushing Antiform. It is also present on Littlejohn Island in the core of the Merepoint Antiform. It occurs on Harpswell Neck southeast of the Cape Elizabeth Fault.

Lithology. The Peaks Island Member is a thick sequence of massive to thin-bedded felsic to intermediate pyroclastic metavolcanics and volcanogenic metasediments. Typical lithologies include:

1) Light gray medium-grained plagioclase-quartz-biotite gneiss with or without K-feldspar, muscovite, and garnet.

2) Medium gray medium-grained plagioclase-quartz-biotite gneiss with or without K-feldspar, garnet, and hornblende.

3) Very light gray medium-grained plagioclase-quartz-K-feldspar-muscovite gneiss and schist.

4) Fine grained massive light to medium gray plagioclase-quartz granofels with or without K-feldspar, biotite, and muscovite. These rocks probably represent fine-grained felsic tuff.

5) Lithologies like 1 and 2 but with abundant twinned plagioclase, K-feldspar, and/or blue quartz in grains 3 to 4 times the size of matrix grains, and representing relict phenocryst fragments (blastophenoclasts) of crystal tuffs.

6) Lithologies like 1 and 2 but with abundant fragments up to 50 cm in larger dimension of the above described metavolcanic rock types, plus dark quartzose metasediments (possible manganiferous metachert). These rock fragments are very strongly elongated parallel to axes of major upright folds (F_2; see section on structure).

7) Light to medium greenish gray calc-silicate gneiss with hornblende, epidote, diopside and occasionally grossularite. This lithology occurs as thin beds, elongate pods, and as thin-bedded lenses up to 50 m thick (as on Moshier Island).

The following lithologies occur as separately mapped (at 1:62,500 scale) lenses and submembers (informal) in the Peaks Island Member (Hussey, work in progress):

1) Very evenly textured massive fine-grained, light gray to white strongly rusty-weathering plagioclase-quartz-muscovite schist (probably representing sulfidic fine-grained felsite ash beds). This lithology has been mapped in two belts close to the western contact of the Peaks Island Member with the Cape Elizabeth Formation extending from South Portland through Cushing, Peaks, and Long Island, to the southern end of the Great Chebeague Island. These belts are approximately 20 m thick each.

2) Sulfidic rusty-weathering quartz-plagioclase-muscovite-biotite-sillimanite-cordierite schist. This occurs as a 50-75 m thick lens between the Macworth Formation and the Peaks Island Member. It has been mapped between Moshier Island and Basket Island, a distance of 8 km.

3) Impure marble in a 20-40 m thick lens within the Peaks Island Member of Littlejohn and Cousins Islands, and a 20+ m thick lens on Moshier Island between the Macworth Formation and the rusty schist lens noted above.

4) Non-rusty medium gray thin-bedded to massive quartz-plagioclase-muscovite-biotite-garnet schist. This lithology has been mapped in a 20 m thick belt on the northwest edge of Whaleboat Island, and a 60 m thick belt on Little Whaleboat Island.

5) Fine- to medium-grained dark gray amphibolite 60 to 70 m thick occurring in a belt extending from Simpson Point in the Pennellville area of Brunswick northeastward to Merrymeeting Bay in Topsham, a distance of 18 km.

Contacts. On the northwestern limb of the Cushing Antiform, the peaks Island Member lies beneath the Cape Elizabeth Formation, and the two rusty-weathering muscovite-schist belts lie close to this contact. On the southeast limb of the Antiform, the Peaks Island is in conformable, locally interfingering, contact with the Wilson Cove Member, and occasionally with the Cape Elizabeth Formation where the Wilson Cove is absent, as at Chimney Rock in Cape Elizabeth 2 km south of Portland Head lighthouse, here the Cape Elizabeth Formation sedimentologically overlies the Peaks Island Member. A 1-2 m thick nonbedded fine granule polymict micaceous metaconglomerate lies between the two units. The interpretation of this contact as a local unconformity is deferred until all members of the Cushing Formation have been discussed. At Cliff Island in Casco Bay the Peaks Island Member is either interbedded with or infolded into the Cape Elizabeth Formation, and here the contact is probably conformable.

The contact of the Peaks Island Member with the underlying Merepoint Member is conformable and is well exposed at the end of Merepoint Neck in Brunswick.

In the area of the Merepoint Anticline, the Peaks Island Member is in fault contact with the Macworth Formation and with the Mount Ararat Member of the Cushing Formation.

Thickness. The width of the outcrop belt of the Peaks Island Member between Birch Island and Merepoint Neck is approximately 1.5 km, and is not complicated by major folding. The dip of primary structures averages about 55°, giving an apparent thickness of about 1.2 km. However, minor parasitic folding, observed at a few localities, has undoubtedly increased the apparent thickness. In view of this the actual thickness of the Peaks Island Member is probably on the order of 700-900 m.

Merepoint Member (new name)

Name and Reference Locality. The Merepoint Member is named from exposures at the very southwestern tip of Merepoint Neck, Brunswick. The reference locality is the 75 m wide belt centered around the triangulation point "Mere" at the tip of the Point. Here the entire thickness of the Member is exposed.

Distribution. The Merepoint Member is exposed in the axial zone of the Merepoint Antiform. It crops out as a single fold nose belt from the northern head of Merepoint Neck to nearly the southern end where it bifurcates into two narrow belts on the limbs of the Antiform. These two belts rejoin at Bustins Island, Freeport because of the southwestward plunge of the Antiform there.

Lithology. The Merepoint Member consists of poorly bedded to massive sulfidic quartz-plagioclase-muscovite-biotite schist with sillimanite and garnet locally. Subordinate to this is non-rusty plagioclase-quartz-biotite-muscovite gneiss and schist similar to the felsic metavolcanics of the overlying and underlying members.

Contacts. The contact with the Peaks Island and Bustins Island Members are conformable, and both are exposed at the type locality on Merepoint Neck.

Thickness. The estimated thickness of the Member is 30 m.

Correlation. The Merepoint Member is correlated on a lithic basis with the Bethel Point Member of the Cushing Formation in the East Harpswell Belt. The Merepoint Member, however is more feldspathic and somewhat less rusty weathering than the Bethel Point Member.

Bustins Island Member (new name)

Name and Reference Locality. The Bustins Island Member is named from Bustins Island, Freeport, 1 km south of the tip of Flying Point. The Member occupies most of the inland portion of the Island but exposures there are poor; consequently the reference localities here designated are the exposures at the southwestern tip of Merepoint Neck in the hinge of the Merepoint Antiform bounded by the two belts of the Merepoint Member on the limbs of the Antiform.

Distribution. The Bustins Island Member is restricted to the hinge zone of the Merepoint Antiform, and is exposed only on the southwestern end of Merepoint Neck, and on Bustins, Pettingill, Williams, and Sow and Pigs Islands.

Lithology. The lithology of the Bustins Island Member differs but little from the Peaks Island Member exposed on Merepoint Neck. It consists of massive to weakly bedded light buff to slightly rusty weathering hard plagioclase-quartz granofels and gneiss with minor biotite and muscovite. It includes occasional thin beds of light to medium greenish gray calcsilicate gneiss with hornblende and diopside.

Contacts. The Merepoint-Bustins Island contact is conformable. Since the Bustins Island Member is exposed only in the core of the Merepoint Anticline, no lower contact is exposed, and the nature of rocks underlying the Member is unknown.

Thickness. The thickness of the exposed part of the Bustins Island Member is estimated to be 75-100 m.

Falmouth-Brunswick Belt

The Cushing Formation in the Falmouth-Brunswick belt is a heterogeneous association of metavolcanic and metasedimentary rocks. The rocks of this belt have been metamorphosed to the sillimanite and sillimanite-K-feldspar grades, are heavily migmatized and are extensively intruded by discordant and concordant pegmatite sills, lenses and dikes. Two members that have been mapped and are hereby defined as formal members are the Mount Ararat and Torrey Hill Members. Two other members are mapped and are correlated with rocks referred to informally as the Nehumkeag Pond and Richmond Corner members by Newberg (1981a, b) from work in the Gardiner and Wiscasset 15' quadrangles. These names are used here informally pending their formal definition by Newberg.

Mount Ararat Member (new name)

Name and Reference Locality. The Mount Ararat member is named from outcrops at and near Mount Ararat in Topsham. The small quarry at the foot of Mount Ararat 150 m S 35° E from the triangulation point on the summit is designated as one of the reference localities for this Member. Another is the excavation behind the large blockhouse on the Brunswick Naval Air Station Annex in Topsham, and the final one is the series of exposures on both sides of the Androscoggin River near the Maine Central Railroad (Lewiston Branch) bridge between Brunswick and Topsham.

Distribution. The Mount Ararat Member is exposed in a 4 km wide belt extending from the Waites Landing area in Falmouth 40 km northeasterly to the Topsham area, and from there through at least the Gardiner 15' quadrangle. In the Topsham area, the Mount Ararat bifurcates around the fold nose belt of the Nehumkeag Pond Member.

Lithology. The Mount Ararat Member consists primarily of light to medium gray non-rusty to slightly rusty weathering quartz-plagioclase-biotite gneiss and granofels with subordinate amphibolite and biotite-hornblende-plagioclase granofels ranging from 2 cm up to mappable lenses 100 to 200 m thick. In the Topsham area and to the north, amphibolite and leucogneiss are commonly interlayered on a scale of 2 to 10 cm. The presence of abundant amphibolite distinguishes the Mount Ararat Member from the Nehumkeag Pond member. The Mount Ararat Member includes a lens up to 100 m thick of very rusty-weathering muscovite-biotite-quartz-graphite schist extending from near Mount Ararat in Topsham northeastward to the edge of the map and beyond.

Contacts. The Mount Ararat-Nehumkeag Pond contact was exposed in the Androscoggin River during construction of the new hydro electric plant between Topsham and Brunswick. This contact is conformable. The contact with the Torrey Hill Member is not exposed, but, because of parallelism of bedding and foliation of rocks of either Members close to the contact, (such as at the I-95-US 1 interchange in Brunswick), the contact is probably conformable.

Thickness. No reliable thickness can be worked out for the Mount Ararat Member because of extensive folding and migmatization that affects the rocks, but may be on the order of 800-1000 m.

Torrey Hill Member (new name)

Name and Reference Locality. The name of the Torrey Hill Member is taken from Torrey Hill in Freeport where typical lithologies are abundantly exposed. This is designated as the reference locality of the Member.

Distribution. Within the map area the Torrey Hill Member is restricted to a 100-400 m wide belt extending from the Waites Landing area of Falmouth northeastward to the Androscoggin River just northwest of Brunswick. It is present at the very north edge of the map in a 100 m wide belt on strike with the first, extending into the Bangor 1x2^{0} map sheet as a series of discontinuous lenses (Newberg, 1981b; Pankiwskyj (1978); and Osberg, personal communication).

Lithology. The Torrey Hill Member consists of non-bedded to very weakly thin-bedded very rusty-weathering sulfidic quartz-muscovite-biotite-graphite-sillimanite-garnet schist, with minor sulfidic quartzose interbeds.

Contacts. From the Waites Landing area, Falmouth, to a point 3 km south of the Androscoggin River, the Torrey Hill Member lies between the Vassalboro Formation and the Mount Ararat Member of the Cushing Formation. North of this point to the termination of this belt it lies between the Richmond Corner Member and the Mount Ararat Member of the Cushing Formation. The belt at the north edge of the map also lies between these two members. The Torrey Hill-Vassalboro contact is inferred to be a premetamorphic folded fault based on consideration of the relative ages of the Vassalboro and Cushing Formations. The contacts with both the Richmond Corner Member and the Mount Ararat Member are inferred to be conformable. None of these contacts have been observed in outcrop.

Thickness. The Torrey Hill Member is approximately 50-75 m thick based on 1) the width of the outcrop along the south bank of the Royal River in Yarmouth, and 2) the dip of schistosity (assumed to be parallel or nearly parallel to original bedding).

Richmond Corner Member (informal name)

Name and Reference Locality. The name "Richmond Corner Member" has been proposed informally by Newberg (1981a, b) for rocks exposed in the vicinity of Richmond Corner in the Gardiner quadrangle just to the north of the map area. Newberg designated exposures north and south of Richmond Corner along U.S. Rte. 201 as reference localities for this map unit.

Distribution. The Richmond Corner Member occupies a wedge shaped outcrop belt apexing 3 km south of the Androscoggin River west of Brunswick where it lies between the Vassalboro Formation and the Torrey Hill Member of the Cushing Formation. The belt widens to 3 km as it leaves the Portland 1x2^{0} map sheet and continues to the north in the Gardiner 15' quadrangle (Newberg, 1981a).

Lithology. The Richmond Corner member within the map area is a heterogeneous association of mostly metasedimentary rocks including:

1) Medium gray quartz-plagioclase-biotite-garnet granulose schist (the predominant lithology);

2) Dark gray amphibolite with thin greenish gray calc-silicate laminae;

3) Pink garnet-quartz-magnetite granofels (coticule).

Lithology 1) closely resembles the high-grade Vassalboro rocks exposed to the west, but the presence of garnet clearly distinguishes Richmond Corner lithologies from those of the Vassalboro; garnet has not been observed in the Vassalboro, except in a very few localities to the south in the Gorham area.

Contacts. The Richmond Corner member is in contact on its west edge with the Vassalboro across the inferred premetamorphic folded fault noted above. On its east edge the Richmond Corner is in contact either with the Torrey Hill Member or where the Torrey Hill is absent with the Mount Ararat Member of the Cushing Formation. Although not observed in outcrop, this eastern contact with these members is inferred to be a conformable stratigraphic boundary.

Thickness. The thickness of the Richmond Corner Member is difficult to estimate because of the unknown amount of repetition of section by minor folding, and because of the truncation of section in a southerly direction against the inferred premetamorphic fault. At the north edge of the map where the outcrop belt is widest, the thickness of the member probably does not exceed 300 m.

Nehumkeag Pond Member (informal name)

Name and Reference Locality. The "Nehumkeag Pond member" was proposed informally by Newberg (1981a, b) for exposures north of Nehumkeag Pond in the Wiscasset 15' quadrangle. He suggested exposures near Goodspeed Cemetery on Route 194 just north of Nehumkeag Pond, and on the ridge paralleling the east bank of Eastern River just north of the village of Dresden Mills, as reference localities.

Distribution. As described by Newberg (1981b) the Nehumkeag Pond member is composed mostly of buff to slightly rusty weathering fine-grained quartz-K-feldspar-plagioclase-muscovite-biotite gneiss. Within the Portland and Bath 1x2^{o} map sheets, the Nehumkeag Pond member is a sequence of thin to medium poorly bedded and massive non-rusty weathering medium to light gray quartz-plagioclase-K-feldspar-biotite$\pm$muscovite gneiss and granofels that have been moderately migmatized and pegmatite-injected. Near the northern edge of the map, centered around the mouth of the Cathance River in Bowdoinham and Topsham is a thin but mappable submember consisting of impure marble and associated rusty-weathering schist. The continuation of this unit has been mapped in the Gardiner 15' quadrangle where it defines a refolded fold near the village of Bowdoinham (Newberg, 1981b). This marble also crops out in Topsham, beneath the north end of the Maine Central Railroad bridge over the Androscoggin River in the inferred nose of this fold.

Contacts. The Nehumkeag-Ararat contact was exposed at the hydroelectric plant on the Androscoggin River at Brunswick during the construction phases of the project. The contact is conformable. The other contact is not known, and the Nehumkeag Pond member is either the youngest or oldest unit of the Cushing Formation in the Falmouth-Brunswick belt, depending on stratigraphic sequence which is as yet uncertain.

Thickness. No reliable thickness for the exposed parts of the Nehumkeag Pond member can be given because of uncertainty of the amount of repetition of section by major and minor folding. The minimum width of outcrop of the member in the map area is 700 m (on the east limb of the Bowdoinham fold). The thickness of the member exposed probably does not exceed 300 m.

East Harpswell-Merrymeeting Bay Belt

This belt, averaging 3.5 km in width, extends from Merrymeeting Bay on the north to Ragged Island between Bailey Island and Small Point on the south and forms the core of the Hen Cove Antiform. This belt includes the greatest variety of lithologies of the Cushing Formation. The southern half of this belt has been described by Hussey (1971b). The writer (Hussey, 1965) informally subdivided the Cushing of this belt into Yarmouth Island member (lowest), Bethel Point member, and Sebascodegan member (highest), and these members are proposed formally here.

Yarmouth Island Member (new name)

Name and Reference Locality. The Yarmouth Island Member is named from exposures along the eastern and southern shoreline of Yarmouth Island, Harpswell. These exposures, and the exposures around the shore of Hen Cove are herewith designated as reference localities for the Member.

Distribution. The Yarmouth Island Member is restricted to the southern half of the East Harpswell-Merrymeeting Bay belt where it occupies the axial portion of the Hen Cove Antiform.

Lithology. The principal lithology of the Yarmouth Island Member is an interassociation of:

1) Plagioclase-quartz-microcline-biotite gneiss,

2) Plagioclase-quartz-biotite-garnet-gedrite gneiss, locally with cordierite, sillimanite, and relict staurolite and andalusite;

3) Plagioclase-quartz-biotite-sillimanite$\pm$muscovite gneiss;

4) Calc-silicate gneiss.

5) Coarse skarn-like reddish gray calc-silicate characterized by irregular intergrowths of clinozoisite, massive grossularite, and minor hornblende. This lithology occurs in zones up to 3 m thick in the upper part of the Yarmouth Island Member and locally at the contact with the Bethel Point Member.

In general quartz is present in amount ranging between 1 and 40%, and is occasionally absent from the paragenesis. Plagioclase is andesine of approximately An_{40} composition. The protolith of these quartz poor feldspar-rich rocks must be pyroclastic volcanic rocks of intermediate composition. The calc-silicate beds reflect intermittent calcareous marine deposition, and the aluminosilicate minerals may reflect the addition of pelitic material from the weathering of volcanic ash.

Minor mappable units (see Hussey, 1971b) in the Yarmouth Island Member include:

1) Gneissic hornblende amphibolite with associated calc-silicate gneiss (two narrow belts, each about 25 to 30 m thick, on the east side of Hen Cove and wrapping around the hinge of the Hen Cove Antiform at the head of Hen Cove, becoming one belt on the west shore).

2) Hornblende-cummingtonite amphibolite forming a 25 m thick belt exposed in the hinge zone of the Hen Cove Antiform on the southern shore of Yarmouth Island.

3) Calc-silicate gneiss with hornblende, diopside, and clinozoisite, closely associated with the amphibolite of unit 2.

Contacts. The contact with the overlying Bethel Point Member is exposed on the north shore of Yarmouth Island, and the two members appear to be conformable. The contact is also exposed on the east shore of Hen Cove. Here the contact is occupied by a 1 m thick skarn-like calc-silicate zone, the significance of which is unknown at present. Because this is the lowest member of the Cushing Formation in the Hen Cove Antiform, the nature of rocks below the Yarmouth Island Member is unknown.

Thickness. The total thickness of the Yarmouth Island Member cannot be estimated because the base of the member is not exposed. The width of outcrop of the member on the south shore of Yarmouth Island between the Hen Cove Anticline and the contact with the Bethel Point Member is approximately 750 m. However, considering the relatively low dip of foliation and the likelihood of minor folding, the total thickness of exposed section is estimated at approximately 200 m.

Bethel Point Member (new name)

Name and Reference Locality. The Bethel Point Member is named from exposures at Bethel Point, East Harpswell, on the west side of Hen Cove. The type locality for the member is the 100 m wide shoreline outcrop on the east side of Hen Cove (see Hussey, 1971b) where both contacts and the entire thickness of the member are exposed.

Distribution. The Bethel Point Member is exposed on the two limbs of the Hen Cove Antiform in the Bethel Point area of Harpswell, on the west side of Yarmouth Island, and in a 1 km wide axial zone in this antiform, extending from Brickyard Cove in Harpswell 25 km northward to Merrymeeting Bay in Brunswick.

Lithology. The Bethel Point Member consists of sulfidic rusty weathering quartz-biotite-muscovite schist with minor 2 to 7 cm thick interbeds of micaceous quartzite. It is lithically consistent throughout its area of outcrop.

Contacts. The contacts of the Bethel Point Member with both the underlying Yarmouth Island Member and the overlying Sebascodegan Member are conformable and sharp.

Thickness. The Bethel Point Member is approximately 100 m thick as determined at the type locality. Here the bedding and schistosity are vertical and are not complicated by minor parasitic folding.

Sebascodegan Member (new name)

Name and Reference Locality. The name is taken from Sebascodegan Island* in Harpswell where this member is the most extensively exposed. The Sebascodegan Member is lithically the most variable member of the Cushing Formation due in part to the large variety of associated lithic types, and in part to rapid east-west (across-strike) facies variations; commonly, subunits mapped on one limb of the Hen Cove Anticline are not present on the other limb, whereas they can be traced for several tens of kilometer along strike. Because of the great lithic variability, no single type or reference locality can be given. Instead, reference localities will be designated below for each of the subunits and variants described.

Distribution. The Sebascodegan Member is limited in outcrop to the limbs of the Hen Cove Antiform between Merrymeeting Bay on the North and Ragged Island on the South.

Lithology. The dominant lithology of the Sebascodegan Member is thin (2-12 cm) weak to well-bedded, and occasionally massive, light gray quartz-plagioclase-biotite granofels and gneiss, occasionally with microcline and minor muscovite. The biotite occurs typically in paper-thin ovoid clots that are usually aligned, producing a distinct mineral lineation. Interbedded with this lithology in lesser amounts are:

1) Calc-silicate gneiss and granofels consisting of hornblende, biotite, clinozoisite, diopside, grossularite, microcline, plagioclase, quartz, sphene, and occasionally calcite;

2) Light to medium gray quartz-plagioclase-biotite-muscovite$\pm$sillimanite gneiss in which sillimanite and sometimes muscovite occur in spindle-shaped prophyroblasts up to 5 mm long in central zones of beds. The reference locality for this lithic association is the 1/2 km long shoreline exposure east of the type locality of the Bethel Point Member in Cundys Harbor area, facing Leavitt and Hen Islands. This lithic association accounts for approximately 3/4 of the member, occurring as the common lithology between various mapped submembers.

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*This island, one of the major inhabited islands of Harpswell, is known colloquially and officially at the local government level as Great Island, but is designated "Sebascodegan Island" on both the Orrs Island 7 1/2' and Bath 15' topographic quadrangles issued by the U.S. Geological Survey, presumably reflecting an earlier name by which this Island was known.

Three general types of amphibolite crop out in several belts within the above described lithology. They are:

1) Pinkham Point type: Medium to dark gray, medium to coarse grained slightly foliated, commonly strongly lineated amphibolite of simple, consistent mineralogy -- andesine and hornblende in equal amounts, and minor amount of biotite and opaques. The texture of the rock in places resembles that of a slightly deformed diorite. Pinkham Point-type amphibolite occurs in two belts, one approximately 100 m wide extending from just north of Pinkham Point on the west shore of Quahog Bay south 6 km to Cedar Ledge in the northern part of Casco Bay. The other is a 25-30 m wide belt 100 m west of the first. The reference locality for Pinkham Point type amphibolite in Pinkham Point. Prior to metamorphism these amphibolites were either andesite flows or diorite sills.

2) Dyers Cove type: Strongly layered and mineralogically variable, characteristically consisting of 1/2 to 12 cm layers of a) hornblende-labradorite-bytownite-biotite amphibolite, locally with abundant cummingtonite and anthophyllite; b) biotite-labradorite-bytownite schist with minor cummingtonite, hornblende, anthophyllite, and prehnite (interleaved with the biotite); c) calc-silicate, containing hornblende, diopside, labradorite-bytownite, clinozoisite, and quartz; and d) impure calc-silicate marble intimately related to c) type layers. A frequent layering sequence of these lithologies is the following: b-a-c-d-c-a-b. This layering sequence, symmetric about the d-type lithology, along with the strongly calcareous plagioclase, suggests that the Dyer Cove type amphibolite may have been an association of thin-bedded magnesian limestone or dolomite and shale, with the layering developing by reaction between these two lithologies during metamorphism. The Dyer Cove type amphibolite includes a 2 m thick bed of marble, locally almost 100% calcite that has been quarried in places for agricultural purposes from several narrow trenches. Dyers Cove type amphibolite forms a major part of the belt of amphibolite extending from Long Point on the west side of Quahog Bay in Harpswell to Merrymeeting Bay in Brunswick. Similar amphibolite and associated impure marble crops out of Ben Island and nearby small unnamed islands in the northwestern part of Quahog Bay. The reference locality for the Dyer Cove type amphibolite is the shoreline exposure of Dyers Cove on the west side of the upper part of Quahog Bay. The marble is typically exposed in a small roadcut on the east side State Highway 24, 3.3 km south of Cooks Corner Brunswick.

3) Cundys Harbor type: Mineralogically similar to the Pinkham Point type, composed of hornblende, andesine, minor opaques and occasionally quartz up to 30%. Texturally, however, it is fine-grained and has a uniform gneissic foliation throughout. The reference locality for this type of amphibolite is the shoreline exposure on East Cundy Point, Harpswell. This amphibolite type forms several irregular lenticular belts up to 150 m wide on the east limb of the Hen Cove Anticline from Cundys Harbor to Merrymeeting Bay. It is also intimately associated with the Dyer Cove type amphibolite from Dyers Cove north to Merrymeeting Bay.

Calc-silicate gneiss forms a minor mappable lens of approximately 200 m maximum width, extending 11 km north from Pole Island in Quahog Bay in Harpswell to Woodward Cove in Brunswick. The rock is a fine-grained light greenish gray plagioclase-quartz-microcline-diopside-hornblende-clinozoisite-biotite gneiss, with minor impure marble and quartz-plagioclase-biotite gneiss. This unit is not present on the east side of the Hen Cove Antiform. The reference locality for this unit is Pole Island.

Separating the calc-silicate gneiss of the Pole Island belt from the Dyer Cove amphibolite belt is a 70 m thick unit of medium dark gray thinly laminated non-rusty to slightly rusty weathering quartz-plagioclase-biotite-tourmaline gneiss and feldspathic biotite quartzite. This unit, also, is not repeated on the east limb of the Hen Cove Antiform. The reference locality for this unit is the head of Orrs Cove on Sebascodegan Island, Harpswell.

Rusty weathering quartz-plagioclase biotite gneiss with minor interbedded calc-silicate gneiss crops out in several thin lenticular belts and one major belt (on the east limb of the Hen Cove Antiform in the vicinity of the upper New Meadows River). These rusty belts are generally closely associated with the various amphibolite types.

Contacts. The Sebascodegan-Bethel Point contact is sharp and conformable. It is exposed at the designated reference locality for the Bethel Point Member. The upper contact with the Cape Elizabeth Formation is exposed on the point of land forming the east side of Doughty Cove at the northern end of Sebascodegan Island; the contact appears conformable but from regional considerations to be discussed, the contact is inferred to be locally an unconformity.

Thickness. The Sebascodegan Member has a minimum width of exposure in the vicinity of Cundys Harbor, Harpswell. Only minor repetition by parasitic folding is found in the section, and the angles of dip are steep, consequently the thickness of the member is probably only slightly less than the width of outcrop, which is approximately 0.7 km. An estimated thickness of 500 m is probably of the correct order of magnitude for the Sebascodegan Member.

Correlations Between Belts

The writer correlates the Bethel Point Member of the East Harpswell-Merrymeeting belt with the Merepoint Member of the South Portland-Harpswell belt on the basis of relative thickness and rusty weathering schistose lithology; however, the Merepoint Member is somewhat more feldspathic than the Bethel Point Member. The Peaks Island Member thus correlates with the Sebascodegan Member, and this is reinforced by lithic similarities in the Pennellville area of Brunswick, and the Long Point area on Sebascodegan Island in Harpswell. In the Pennellville area a moderate amount of calc-silicate granofels and gneiss is present as thin greenish beds in the Peaks Island Member, making it very similar to the Sebascodegan Member. In the Long Point area of the East Harpswell-Merrymeeting belt, the Sebascodegan Member frequently preserves pyroclastic structures very similar to the Peaks Island Member of the South Portland area. The general difference between members of the two belts would suggest that the South Portland-Harpswell belt was closer to a center of volcanic activity at the time of deposition, and that the East Harpswell-Merrymeeting belt was a slightly more distal apron of marine reworked volcanic detritus.

Essentially no correlations can be drawn between the Falmouth-Brunswick belt and the other two beyond the general quartzo-feldspathic composition of all three belts. In part, this lack of correlation may be due to the higher grade of metamorphism and very extensive migmatization characteristic of the Falmouth-Brunswick belt.

Nature of the Cushing-Cape Elizabeth Contact

The following relatives have suggested to the writer (Hussey, 1981) that the Cushing-Cape Elizabeth contact is, locally, at least, an unconformity:

1) At Chimney Rock along the Cape Elizabeth shoreline approximately 1 km south of Portland Head Light, the basal 1-2 m of the Cape Elizabeth Formation is a non-bedded quartz-mica schist with abundant highly stretched granule-sized clasts of light and dark-colored rock fragments of Cushing affinity, plus quartz and feldspar. This granule zone is interpreted to be a basal granule conglomerate of the Cape Elizabeth Formation deposited unconformably on the Cushing Formation. No angularity, however, can be demonstrated here between the two formations.

2) In the Pennellville area of Brunswick, the Cape Elizabeth-Cushing contact, when traced northward toward the Brunswick Naval Air Station, gradually transgresses across, thus cutting out, approximately a 200-300 m section of the upper part of the Cushing, including the whole of the Wilson Cove Member. This may be interpreted as either 1) a fault contact or 2) a low angle unconformity in which the Cape Elizabeth was laid down on an eroded and gently tilted Cushing terrane. The writer presently favors the latter interpretation.

Locally, the contact appears conformable as for example on Cliff Island in Casco Bay. Here, the Cape Elizabeth and Cushing are interlayered in sequences 1-2 m thick over an interval of 10-20 m. They may be stratigraphic interbeds or tight infolds of the Cushing in the basal part of the Cape Elizabeth. No fold hinges were observed here. the granule zone noted at Chimney Rock, discussed above, is absent at this locality.

Cape Elizabeth Formation

Name and Reference Locality. Katz (1917) named the Cape Elizabeth Formation for shoreline exposures in the town of Cape Elizabeth. He did not specify any particular part of the shoreline as a reference or type locality. The writer proposes as the reference locality for the formation the shoreline exposure extending 1 km south from Pond Cove (1.7 km S 15° E of Portland Head Light, Casco Bay 15' quadrangle).

Distribution. The Cape Elizabeth Formation is exposed in fault-controlled belts from Saco eastward to the Boothbay Harbor area, and northward from Phippsburg to the Bangor area well to the north of the map area. The maximum width of exposure is approximately 25 km in the area between West Bath, and Southport Island near Boothbay Harbor. The eastern-most exposure of the Formation is on Rutherford Island, South Bristol (Kirk, 1971).

Lithology. The Cape Elizabeth Formation can be observed in all grades of metamorphism from the chlorite zone to sillimanite-K-feldspar zone. In the chlorite zone the Cape Elizabeth is characteristically a medium buff-weathering finely crenulated, limonite-speckled quartzose phyllite with 3 to 10 cm interbeds of dark gray crenulated chlorite phyllite. On fresh surfaces the quartzose beds are medium bluish gray. Limonite speckling is due to the weathering of ankeritic carbonate which is abundant in addition to calcite. In the Two Lights State Park area of Cape Elizabeth beds of calcite and ankerite-bearing buff weathering feldspathic quartzite up to 50 cm in thickness are abundant in the sequence. Occasional 5 to 15 cm beds and lenses of punky brown-weathering carbonate-rich rock are present, particularly in the vicinity of Two Lights State Park. In the biotite zone, the lithology of the Formation is similar to that in the chlorite zone, except that the quartzose beds weather gray, not to buff colored.

In the garnet and andalusite-staurolite zones the Cape Elizabeth is thin-bedded (1 to 3 cm) medium gray fine-grained quartz-plagioclase-biotite-garnet-schist with occasional 1 to 20 cm interbeds of micaceous and feldspathic quartzite, and sparing lenses of calc-silicate granofels. In general, staurolite and andalusite are not abundant.

In the staurolite-sillimanite and sillimanite zones the principal lithology is medium gray quartz-plagioclase-muscovite-biotite schist with thin interbeds of muscovite-biotite-sillimanite±staurolite quartz schist, feldspathic and micaceous quartzite, occasional calc-silicate granofels, and sparing 5 to 25 mm beds of reddish gray garnet-quartz-biotite granofels (coticule). In the Orrs Island area of Harpswell, the Cape Elizabeth includes very sparing layers of boudined amphibolite, occasionally chlorite-rich. These may represent original basaltic ash beds or possibly thin syntectonic premetamorphic basic sills. In the sillimanite-K-feldspar zone K-feldspar makes its appearance in the pelitic interbeds and zones of pelite, and the entire sequence is strongly migmatized and injected with pegmatite.

In the Harpswell area, sulfidic metapelite is mapped at the base of the Formation (Hussey, 1971b). This unit consists of moderately to very rusty weathering muscovite-biotite-garnet-quartz schist with abundant staurolite or sillimanite depending on the metamorphic grade. This lithology forms 1) a lens up to 250 m wide between the Wilson Cove Member of the Cushing and the principal lithology of the Cape Elizabeth Formation on the west side of Harpswell Neck; 2) a lens up to 500 m wide between the Cushing Formation and the quartzose Cape Elizabeth in the area between Cundys Harbor, Harpswell and Fosters Point, West Bath; and 3) a 200 m wide lens at the same stratigraphic horizon from Gun Point, Sebascodegan Island, Harpswell, northward for approximately 8 km. Elsewhere the quartzose Cape Elizabeth lies in direct contact with the various members and subunits of the Cushing Formation.

Two minor, but distinctive, units within the quartzose Cape Elizabeth are mapped by the writer in the Arrowsic-Phippsburg-Bath area. One of these, typically exposed on the northern shore of The Basin in Phippsburg, consists of an intimate association of light gray marble; calc-silicate granofels, gneiss, and skarn; and dark greenish gray amphibolite. This unit includes the Phippsburg grossularite garnet locality that is well known to both amateur and professional mineralogists. The other unit, in contact with the first, consists of dark gray biotite-quartz-plagioclase-sillimanite schist with infrequent micaceous quartzite beds. The reference exposure of this unit is to be seen on State Highway 209 on Pitchpine Hill, Arrowsic, just southeast of Bench Mark 124. Neither unit exceeds 50 m in thickness.

Contacts. The Cape Elizabeth-Cushing contact is interpreted to be at places a slightly tilted angular unconformity and at other places a conformable contact as described above. At two exposures of this contact on the northwestern shore of Peaks Island, graded beds in the Cape Elizabeth Formation within three feet of the contact indicate that the Cape Elizabeth lies on top of the Cushing.

The Cape Elizabeth-Spring Point contact is sharp and conformable. It is exposed on the north shore of a small cove on the west side of Bailey Island 0.37 km N 70 W of the triangulation point "Star".

Thickness. The Cape Elizabeth Formation is extensively folded and thus a precise determination of thickness cannot be made. The narrowest outcrop belt of the formation occurs in the town of Cape Elizabeth on the southeast limb of the Cushing Anticline. Here bedding is steep to vertical and the width of the outcrop belt is approximately 500 m. Assuming some repetition by minor folding, the thickness is estimated to be about 350 m.

Spring Point Formation

Name and Reference Locality. The Spring Point Formation was originally named the Spring Point Greenstone by Katz (1917) for exposures at Spring Point in South Portland. Bodine (1965) referred to this unit as the Spring Point Formation and this usage has been followed by the writer (Hussey, 1968, 1971a, 1971b). The Formation includes other rock types than just metabasalts, nor are the metabasalts universally green in color; hence the preference for the non-lithic designation "formation".

The type locality for the Spring Point Formation is the shoreline exposure on the southeast side of the campus of Southern Maine Vocational Technical Institute at Spring Point in South Portland. Here the Spring Point is at intermediate grade of metamorphism. A reference locality for the Spring Point at lower grade is the exposure in the gravel pit on the southeast side of Scotow Hill in Scarboro. Here the contact with the Scarboro Formation is exposed. A reference locality for the Spring Point at higher grade of metamorphism is the shoreline exposure on the east side of Harpswell Neck 1.6 km north of Stover Point. Here the Spring Point has been metamorphosed to sillimanite grade and the upper non basic metavolcanics and metasediments are exposed.

Distribution. The Spring Point Formation is exposed on the limbs and antiformal hinges of F_2 folds from Scarboro north to Harpswell. Amphibolite belts in the Boothbay Harbor region may correlate with the Spring Point Formation, the eastern-most exposures of this formation thus being on Rutherford Island, South Bristol. These outcrop belts range in width from 50 m to 1.3 km. The Formation is absent in the Saco area around the nose of the Saco Syncline.

Lithology. In the chlorite and biotite zones of metamorphism, the Spring Point Formation consists of medium greenish gray chlorite-white mica-garnet phyllite. The garnet is spessartite, hence its appearance at the lower metamorphic grade. In the garnet and staurolite-andalusite grades the Formation consists of fine-grained olive-greenish-gray actinolite or hornblende-biotite amphibolite. Locally, flattened and elongate blastopyroclasts of light gray metafelsite are common, particularly on the south side of Great and Little Diamond Islands. There, many of the clasts resemble the blue-quartz-bearing metafelsite crystal tuffs of the Peaks Island Member of the Cushing Formation. In many places, particularly at the type locality at Spring Point, the blastopyroclasts are small, very thin (1 to 4 mm), and resemble gneissic folia. At sillimanite and higher grade, the Formation consists of dark green amphibolite locally with large anhedral garnet porphyroblasts and poikiloblasts. Associated with the amphibolite at this grade in the Harpswell sound area are the following:

1) medium greenish gray schist with chlorite and light green amphibole;

2) plagioclase-quartz-cummingtonite-biotite gneiss with anthophyllite locally;

3) hornblende-biotite-garnet amphibolite with coarse garnet-biotite schist partings; and

4) reddish gray thinly banded garnet-quartz-plagioclase-biotite granofels (essentially coticule) with hornblende amphibolite interlayers.

An upper member of the Spring Point Formation is mapped in the Harpswell area by Hussey (1971b). This unit consists of fine-grained light gray thin-bedded quartz-plagioclase-biotite-muscovite-garnet gneiss and granofels; quartz-plagioclase-muscovite-biotite schist; calc-silicate gneiss; and plagioclase-quartz-biotite-hornblende gneiss transitional to amphibolite. Similar lithology also characterizes the Spring Point Formation exposed on Cliff Island in Casco Bay.

The quartzo-feldspathic rocks of the upper member of the formation represent volcanogenic metasediments and felsic metatuff. Amphibolite and chlorite-rich rocks of the main part of the formation were basic tuff and agglomerate prior to metamorphism.

Contacts. The Spring Point Formation has sharp and conformable contacts with both the underlying Cape Elizabeth Formation and overlying Diamond Island Formation or Scarboro Formation where the Diamond Island is missing. At the Scotow Hill locality mentioned above the contact between the Spring Point Formation and the Scarboro Formation is exposed (the writer originally interpreted this to be the contact between the Spring Point and Cape Elizabeth Formations (Hussey, 1971a), but now assigns the metapelites west of the Spring Point Formation to the Scarboro Formation). In the Scarboro Formation one meter west of the contact is a 10 cm graded bed indicating that the Spring Point is overlain by the Scarboro Formation.

Thickness. The Spring Point Formation ranges from 0 to an estimated 150 m in thickness.

Diamond Island Formation

Name and Reference Locality. The Diamond Island Formation (originally referred to as the Diamond Island Slate) was named by Katz (1917) for exposures on both Great and Little Diamond Islands. On Little Diamond Island the Formation is exposed along part of the southeast shoreline, and on Great Diamond Island the Formation is exposed in a deeply indented cove on the northeast end of the island. The best and most readily accessible exposures, however, are along the southeast shore of Spring Point, beside Southern Maine Vocational Institute campus, and this is herein designated the type locality for the Diamond Island Formation. Here, both contacts and the entire thickness of the Formation are clearly exposed.

Distribution. The distribution of the Diamond Island Formation very closely parallels that of the Spring Point Formation, cropping out in narrow belts between the exposure belts of the Spring Point and Scarboro Formations in the South Portland-Cape Elizabeth area, on Barnes Island near the southwestern tip of Harpswell Neck, at Basin Point at the end of Harpswell, and in the Small Point area. The Diamond Island Formation is absent generally in the Scarboro-Saco area, and on both flanks of the Harpswell Sound Synform in Harpswell.

Lithology. The Diamond Island Formation consists of black pyritiferous rusty-weathering quartz-muscovite-graphite phyllite. It is nonbedded. Paper-thin quartz veins crenulated to varying degrees permeate the rocks. At the type locality as here designated, the Diamond Island includes 0.75 m metalimestone bed in essentially the middle of the Formation. This bed has not been observed elsewhere.

Contacts. The contacts of the Diamond Island Formation with the Scarboro Formation above and the Spring Point Formation below, are conformable and sharp.

Thickness. In the South Portland-Middle Casco Bay area the Diamond Island Formation is approximately 35 m thick, fairly abruptly pinching out to the southwest in the Scarboro area. At Barnes Island it is about 1 m thick on the west limb of the Barnes Island Antiform; at Basin Point it is approximately 10 m thick; and at Small Point it is approximately 20 m thick.

Scarboro Formation

Name and Reference Locality. The Scarboro Formation was named by Katz (1917) for exposures in the seacliff at Higgins Beach in the town of Scarborough*. A more complete section of the Formation is exposed along the Cape Elizabeth shoreline between Broad Cove and Trundy Point and this is designated as the reference locality of the Formation. This section exposes most of the lithologies present in the Formation plus both the upper and lower

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*We retain Katz's spelling for the Formation even though the town has officially adopted the spelling of "Scarborough".

contacts. Katz (1917) originally referred to the Formation as the Scarboro Phyllite; however, because of higher grade of metamorphism in the Harpswell area relative to Katz's reference locality at Higgins Beach, rocks of the Formation are better described as schist. For this reason, Bodine (1965) and Hussey (1971a, b) have amended the name to Scarboro Formation.

Distribution. The Scarboro Formation crops out extensively from Saco to Portland, South Portland, and Cape Elizabeth. It is present on Great Diamond, Great Chebeague, Barnes, Eagle, Upper Flagg, Cliff, Bates, and Ministerial Islands in Casco Bay. It is exposed on the eastern and northern shores of Potts Harbor of Harpswell Neck, and on the western shore of Bailey Island, Harpswell. It is present in the southern part of Phippsburg at Cape Small and in the southern part of Georgetown Island. Kirk (1971) in the Boothbay area mapped two small belts of rusty metapelite which he correlated with the Cape Elizabeth but which correlate with the Scarboro Formation.

Lithology. In the Scarborough-Saco area where the Formation is at chlorite and biotite grades of metamorphism, the Scarboro Formation is a very crenulated dark gray chlorite-muscovite phyllite. Both rusty and non-rusty varieties are present. Bedding is very seldom observed. In Cape Elizabeth-Casco Bay-Harpswell area, in garnet and staurolite-andalusite grades of metamorphism, the following lithologies are present:

1) Light gray muscovite-biotite-garnet phyllite to schist;

2) Dark gray muscovite-chlorite-biotite-garnet phyllite and schist, locally with chloritoid, andalusite, and staurolite;

3) Mottly medium greenish and purplish gray muscovite-biotite-chlorite-garnet schist;

4) Very rusty weathering sulfidic equivalents of 1) and 2) above;

5) Medium greenish gray chlorite-biotite-garnet phyllite very similar in appearance to the low grade phyllites of the Spring Point Formation. This lithology is separately mapped as an unnamed member of this Formation in the Portland quadrangle (Hussey, 1971a).

A relatively persistent 10 to 35 m thick fine grained gray ribbony thin bedded metalimestone very similar in appearance to the Spurwink Metalimestone occurs close to the base of the Scarboro Formation. This unit is exposed on Great Diamond Island, at Spring Point, on the northeast end of Bailey Island, and in the southern part of Cape Elizabeth close to Crescent Beach and Two Lights State Parks.

In the southern part of Phippsburg, rocks correlated with the Scarboro Formation on the basis of lithic sequence are very aluminous schists with abundant staurolite and either poikiloblastic andalusite up to 8 cm in diameter or felted masses of fibrolitic sillimanite depending on grade of metamorphism.

In the Georgetown area, the nature of the Scarboro Formation is complicated by a possible major facies change. East of the axis of the Georgetown synform the Scarboro consists of metapelite very similar to that in

Phippsburg. Sillimanite is abundant and relict staurolite and poikiloblastic andalusite are present. West of the axis of the synform the rocks of the Formation are mostly quartz-plagioclase-biotite-muscovite$\pm$garnet schist with minor interbeds of metapelite very similar to the Cape Elizabeth Formation. Both lithologies occupy the down-plunge side of the synform relative to the amphibolite that is correlated with the Spring Point Formation.

Contacts. The Scarboro Formation conformably and sharply overlies the Diamond Island Formation where the latter is present, and where not, conformably and sharply overlies the Spring Point Formation. The Scarboro is overlain conformably by the Spurwink Metalimestone, with thin intervals of Scarboro-type phyllite in the basal 5 m of the Spurwink.

Thickness. The Scarboro Formation is probably about 200 m thick. No accurate estimate of thickness can likely be made due to the extensive minor folding of the formation and the incompetency of the lithology.

Spurwink Metalimestone

Name and Reference Locality. The name "Spurwink Limestone" was proposed by Katz (1971) for exposures at two localities on the banks of the Spurwink River between Cape Elizabeth and Scarboro. A more accessible and complete section of the formation is exposed at Pebbles Point in Cape Elizabeth, and the writer proposes this as the reference locality for the formation. The writer further proposes that the name of the formation be amended by prefixing "Meta" before the word "limestone" so as clearly to indicate the metamorphosed nature of the unit.

Distribution. The Spurwink Metalimestone is exposed in the following areas:

1) in a narrow belt on Great Chebeague, Little Chebeague, Cow, and Great Diamond Islands and the Knightville area of South Portland;

2) a narrow belt in South Harpswell from Stover Point through Potts Point to low ledges just west of Haskell Island, Harpswell;

3) the limbs of the doubly-plunging Higgins Beach syncline, Scarborough;

4) a narrow belt approximately 2 km long just northwest of Oak Hill, Scarboro;

5) the Trundy Point-Peabbles Point area of Cape Elizabeth;

6) a very narrow belt on the west side of Jewell Island. This is a critical exposure as regards the distinction between the Jewell and Scarboro Formations as will be discussed under the section on the Jewell Formation.

Lithology. The Spurwink Metalimestone typically is a medium gray thin, ribbony-bedded metamorphosed limestone with interbeds of quartz-biotite-garnet phyllite and rusty-weathering dark gray carbonaceous phyllite. The rock is very fine-grained, and even at staurolite grade does not have the granoblastic texture in hand specimen characteristic of a marble, hence the retention of the term "limestone" in the name of the Formation.

Contacts. The Spurwink Metalimestone conformably overlies the Scarboro and is conformably overlain by the Jewell Formation.

Thickness. The Spurwink Metalimestone varies from 25 to 100 m in thickness. The thinnest observed belt is on Jewell Island where only about 25 m of the Metalimestone separate otherwise indistinguishable phyllites of the Jewell and Scarboro Formations. The Spurwink is thickest on Great Diamond Island.

Jewell Formation

Name and Reference Locality. The Jewell Formation was named the Jewell Phyllite by Katz (1917) for extensive exposures on Jewell Island. The name has been modified by Bodine (1965) and the writer (1971a, b) to Jewell Formation on the basis that some of the rocks of the unit at higher metamorphic grades are characteristically fine-grained schist rather than phyllite.

The choice by Katz of Jewell Island for the type locality for the Jewell Formation was questionable. The Jewell and Scarboro Formations are essentially identical lithologically and can only be distinguished if the Spurwink Metalimestone can be mapped between them. Although a metalimestone has been mapped on the west side of the Island, it is much thinner than the characteristic thickness of the Spurwink (20 vs 100 m) and has much more rusty interbedded phyllite than noted elsewhere. These differences raise the possibility that this metalimestone may be one of the minor lenses such as has been mapped in the Scarboro Formation in the Cape Elizabeth area. The writer therefore designates as the reference locality for the Jewell Formation the exposures on the northwest side of the Spurwink belt on Great Diamond Island. The name "Jewell" is retained for this formation because it has been extensively used in the literature; furthermore, the writer makes the tentative assumption that the thin metalimestone on the west side of Jewell Island is the Spurwink Metalimestone and that the phyllites east of it are part of the Jewell Formation.

Distribution. The Jewell Formation underlies the core of the doubly-plunging Higgins Beach Synform in Scarboro. It crops out on the northwestern shores of Great Diamond, Little Chebeague and Great Chebeague Islands in Casco Bay. It occupies the core of the Harpswell Sound Synform from Stover Point, Harpswell, southward, including all the area of Haskell Island.

Lithology. The Jewell Formation is essentially identical in lithology to the Scarboro Formation. It consists of rusty and non-rusty both light muscovitic and dark carbonaceous and muscovitic phyllites and schists, and occasional horizons of medium greenish gray chloritic phyllite (very similar to low grade Spring Point Formation). Garnet is common throughout these phyllites, and staurolite, andalusite, and chloritoid are present at proper metamorphic grade and chemical composition.

Contacts. The contact between the underlying Spurwink Metalimestone and the Jewell Formation is conformable and gradational over a meter or so. The contact with the Macworth-like lens on Great Chebeague has not been observed, but appears to be conformable based on lack of structural discordancy.

Thickness. The thickness of the Jewell Formation cannot be reliably determined because of extensive folding and faulting, but probably is of the order of 150-200 m.

Macworth Formation

Names and Reference Locality. Katz (1917) proposed the name Macworth Slate for rocks typically exposed on Macworth Island in Casco Bay. However, since none of the rocks assigned to this formation are slaty, the writer (Hussey, 1968) and Bodine (1965) both refer to it as the Macworth Formation.

The reference locality for the Macworth Formation is the shoreline of Macworth Island.

Distribution. The Macworth Formation crops out on Macworth, Clapboard, and Sturdivant Islands and most of Cousins Island. It is present in the Waites Landing area of Falmouth and extends southwest into the vicinity of the Portland Jetport at South Portland. It may extend northward into the South Freeport area, and may be present on the northwest end of Great Chebeague Island (see following sections).

Lithology. The Macworth Formation consists of thin-bedded to paper-thin laminated drab-brown slightly chalky-weathering calcareous and quartzose phyllite, dark gray phyllite, quartzose phyllite with 2-4 mm long granules of finely granulated quartz and feldspar concentrated in the central parts of beds, minor rusty-weathering phyllite similar to the Scarboro and Jewell Formations, and occasional thin beds of felsic metatuff. On the western side of Cousins Island thin calc-silicate beds are present and there the Macworth resembles thinly bedded variants of the Vassalboro Formation.

On the northwest side of Great Chebeague Island the writer maps a lenticular belt approximately 200 m wide and 2 km long of medium brownish gray, slightly chalky weathering slightly calcareous quartz-biotite phyllite. This unit is surrounded by the typical micaceous phyllites of the Jewell Formation and is interpreted to occupy the trough of a synform, and thus to be the highest stratigraphic unit of the Casco Bay Group. The writer tentatively interprets this to be the lower part of the Macworth Formation, thus tying the otherwise fault-bounded Macworth into the Casco Bay sequence.

Contacts. The main belt of the Macworth Formation is separated from the Cushing Formation on its west side by the post-metamorphic Flying Point Fault (Bodine, 1965; Hussey, 1981). At Bartlett Point, Falmouth, and on Sturdivant Island short intervals of cover separate high grade migmatized leucogneiss and amphibolite of the Mt. Ararat Member of the Cushing Formation from the Macworth at much lower (possibly biotite) grade. The nature of the eastern contact is much less certain but is inferred to be a fault for the following two reasons:

1) along this side the Macworth is in contact with the Cape Elizabeth, Spring Point, and Cushing Formations from south to north, respectively; and

2) regional metamorphic isograds established for metapelitic units of the Casco Bay Group to the east of the Macworth belt trend approximately N 75 E, and the garnet, andalusite-staurolite, and sillimanite-staurolite isograds strike toward the Macworth belt which shows little mineralogical or textural change throughout its strike belt.

The contact of the Jewell Formation with the infolded unit on Great Chebeague Island correlated with the Macworth is obscured by a few meters of cover, but appears conformable.

MERRIMACK GROUP

Introduction

The name "Merrimack Group" was first used by C. H. Hitchcock in 1870 (Billings, 1956, p. 43). It was applied to an undifferentiated sequence of quartzites and quartzose slates and phyllites as typically exposed along the Merrimack River Valley near Salisbury, Massachusetts. Billings includes in the Group the Kittery, Eliot, and Berwick Formations mapped by Katz (1917) in the southwestern Maine-Southeastern New Hampshire area, and this usage is followed by the present writer.

Kittery Formation

Name and Reference Locality. This formation was first mapped by Katz (1917) who referred to it as the Kittery Quartzite. The name was changed to Kittery Formation by Woodard (1957) on the basis that true quartzites are not characteristic of the formation. The Formation was named from the town of Kittery where outcrops are abundant. Katz gave no specific area as type locality and the writer hereby proposes as the reference locality for the Kittery Formation the roadcut exposures in the town of Kittery at and around the junction of Maine Highway 103 and I-95.

Distribution. In Maine, the Kittery Formation extends in a belt 5 to 16 km wide along the cost from Gerrish Island in Kittery to Kennebunkport. This belt extends to the south in New Hampshire from Kittery to the vicinity of Hampton and beyond. The Kittery is also exposed in an anticlinal belt, interrupted by the Exeter Diorite, from Dover to Exeter just south of the map area.

Lithology. The Kittery Formation consists of a variably thin to thick bedded association of the following rock types:

1) buff-weathering very fine-grained thinly-laminated calcareous and feldspathic quartzite;

2) fine-grained to flinty textured hard chocolate-brown to medium gray feldspathic, micaceous (chlorite and/or biotite) and calcareous quartzite;

3) dark gray or brownish gray chlorite or biotite phyllite. Lithologies 2 and 3 commonly form graded beds with 2 grading upward into 3 in couplets ranging from 1 cm to 1 m or slightly greater. The thicker quartzite beds of both 1 and 2 type commonly have relict detrital sand to fine granule sized grains of feldspar, quartz, and possibly rock fragments in the basal 2 to 4 cm of a bed.

A detailed sedimentological study by Rickerich (1983) of the Kittery Formation in the Kittery area has demonstrated a wealth of preserved sedimentary structures including graded bedding, parallel and cross lamination, small-scale channel cut and fill, load and flow flames, rip-up clasts, load casts, and oval carbonate concretions. Bedding thickness and style vary rapidly in the stratigraphic pile suggesting that the Kittery Formation accumulated mostly as turbidites in a deep sea submarine fan environment. Paleocurrent azimuth average for Kittery turbidites determined from cross-lamination is 264° (Rickerich, 1983) indicating transport down a westerly-facing slope from an eastern source area. Interbedded with the graded turbidites are occasional thick ungraded, well sorted, and strongly cross-laminated beds interpreted by Rickerich to be contourites. Average paleoccurrent azimuth for these beds is 308°.

Contacts. The Kittery Formation is in fault contact with the Rye Formation as described above. The contact between the Kittery and Eliot Formations can be observed at low tide in ledges along the Maine side of the Piscataquis River near the mouth of the Great Works River in South Berwick. The contact there appears conformable with the hard feldspathic quartzites of the Kittery grading into the slightly more phyllitic and essentially unbedded lower part of the Eliot. The sedimentary topping direction at this contact is not known.

Thickness. The thickness of the Kittery Formation is difficult to estimate because of the extensive folding, both upright and recumbent, of the Formation. Katz (1917) gave an estimate of 600 m which may be low. Based on the approximate 5 km width of the outcrop belt between the Eliot and Rye Formations along the Piscataquis River in the Kittery area, the thickness may be on the order of 1000 to 1500 m.

Eliot Formation

Name and Reference Locality. Katz (1917) proposed the name Eliot Slate for rocks exposed in the town of Eliot, southwestern Maine. Freedman (1950) and Billings (1956) refer to the unit as the Eliot Formation because slate is not a rock type present and the texture varies significantly in the different metamorphic grade zones. No type locality for the Eliot Formation was given by Katz. Due to the scarcity of outcrops in Eliot, a reference locality in that town is not warranted. The best exposures of the formation occur in extensive road cuts at the intersection of U.S. Highway 4 and New Hampshire Highway 155 in the town of Lee, New Hampshire, and this is designated as the reference locality for the Eliot Formation.

Distribution. The Eliot Formation crops out in two separate belts. The western belt extends from just east of Epping, New Hampshire north-northwest through Dover, New Hampshire to North Berwick, Maine. This belt narrows from approximately 7 km in the Epping area to 1 km in the North Berwick area. The continuation of this belt northward from the Webhannet Pluton is essentially unknown because of scarcity of outcrop. An isolated outcrop of carbonaceous black phyllite essentially identical to the Calef Member of the Formation in the Epping, New Hampshire area crops out in the channel of the Mousam river in West Kennebunk and may correlate with this belt of Eliot thus extending it 3 km north of the Webhannet Pluton. Its continuation to the northeast is uncertain.

The eastern belt of the Eliot Formation extends from the south end of the map area where it is about 5 km wide, northward to Eliot, Maine, where it divides into eastern and western synclinal subbelts. The eastern of the two, averaging 5 km in width extends to the south edge of the Agamenticus complex in York, and the western one, approximately 3 km wide, extends northward to the town of South Berwick, Maine, where it is separated from the Epping-North Berwick belt by a narrow zone of the Kittery Formation.

Lithology. At chlorite grade, the Eliot Formation consists of thin bedded alternations of medium buff-gray weathering, medium bluish gray ankerite and calcite-bearing quartz-mica phyllite, and dark gray finely-crenulated phyllite. Near the contact with the Kittery Formation, the dark phyllite is lacking and the Eliot there consists of massive quartz-mica-carbonate phyllite. At higher grade the Formation consists of thin-bedded alternations of fine-grained quartz-plagioclases-biotite-actinolite granofels and dark brown biotite schist or phyllite.

In New Hampshire, Freedman (1950) mapped an upper unit of the Eliot Formation, the Calef Member, consisting principally of black graphitic phyllite and minor green quartz-chlorite phyllite. The Calef Member crops out in a 1 km wide belt extending from Brentwood Corner to Lee. The isolated outcrop of black phyllite in the Mousam River near West Kennebunk, Maine, is lithically identical to the Calef Member, and is tentatively included with the Eliot Formation. This is the only occurrence of Calef lithology known north of Lee, New Hampshire.

Contacts. The contact of the Eliot and Kittery Formations is exposed at the confluence of the Piscataquis and Great Works Rivers in South Berwick. There, the hard quartzitic beds of the Kittery grade conformably into the quartz-mica phyllites of the Eliot over an interval of approximately 1 m. The contact of the Eliot and Berwick Formations has not been observed but is inferred to be conformable on the basis of structural conformity of the two Formations on either side of the inferred position of the contact.

Thickness. Freedman (1950) estimated the thickness of the Eliot Formation in the Mt. Pawtuckaway quadrangle, New Hampshire, to be about 2000 m. Although this may be a reasonable figure for that area, where the outcrop belt exceeds 7 km, it is too thick for the belt mapped from south Berwick to North Berwick, Maine, where the outcrop belt is less than 1 km. Here the thickness of the Eliot is probably on the order of 250 m. The Calef Member in New Hampshire is probably about 100-200 m thick.

Berwick Formation

Name and Reference Locality. Katz (1917) proposed the name "Berwick Gneiss" for rocks in southeastern New Hampshire and southwestern Maine occupying a belt between the Gonic Formation on the west and the Eliot or Kittery Formations on the east. He considered the formation to be more metamorphosed and deformed than the Kittery or Eliot Formations and hence older, (suggesting a possible Precambrian age). Freedman (1950), however, showed the probable conformability of the Berwick with adjacent formations and renamed it the Berwick Formation, regarding it as the highest unit of the Merrimack Group.

The exposure in the Salmon Falls River between Berwick, Maine, and Somersworth, New Hampshire, is here designated the reference locality for the Formation.

Distribution. The Berwick Formation occupies a belt averaging 6 km in width and extending from the southern edge of the map area near Epping, New Hampshire, northeast to the outcrop belt of the Casco Bay Group. It is exposed between the northeast side of the Biddeford Pluton and the Casco Bay outcrop belt.

Lithology. The Berwick Formation has been metamorphosed from biotite (?) to sillimanite grade as determined on the basis of rare pelitic interbeds. characteristically the Berwick Formation is an interbedded association of quartz-plagioclase-biotite-amphibole granofels and calc silicate gneiss and granofels. The biotite granofels is very fine-grained, medium brownish to purplish gray, and very hard. Calc-silicate beds are light medium greenish gray on fresh surface and weather to light buff gray. Calc silicate minerals include zoisite, diopside, hornblende or actinolite, and grossularite (quite rare and usually associated with compositionally-zoned concretions). Bedding thickness is variable, commonly ranging from 5 to 40 cm; however, significant portions of the formation are massive. Graded bedding is occasionally seen but is not as common as in the Kittery Formation.

In the Pawtuckaway 15' quadrangle in New Hampshire, Freedman (1950) mapped a 2-4 km wide zone southeast of the Massabesic Gneiss and Rochester Pluton between Raymond and south Barrington as part of the Littleton Formation. Billings (1956), however, has correlated this belt with the Berwick Formation. Rocks of this belt which the present writer includes as an unnamed member of the Berwick, are not particularly typical of either the Berwick or the locally mapped variety of Littleton (Pittsfield and Jenness Pond Members). These rocks consist of medium gray salt and pepper textured quartz-plagioclase-biotite±hornblende granofels and calc-silicate granofels typical of high grade Berwick, but frequently interbedded with this lithology in zones 0.5 to 5 m thick, is dark medium gray granulose biotite-quartz-plagioclase-sillimanite schist which is atypical of the Berwick Formation in Maine. The presence of these pelites led Freedman to the Littleton correlation, but Billings preferred a Berwick correlation on the basis of the dominance of biotite granofels. These rocks appear to be abruptly much coarser grained than the rocks of the belt of typical Berwick on the southeast side of the contact as mapped by Freedman leaving open the possibility that these different aspects of the Berwick Formation are not in depositional contact.

Freedman mapped a thin (approximately 300 m) zone of silvery muscovite-biotite-garnet-staurolite±sillimanite schist within this belt of atypical Berwick between Raymond and Nottingham. He referred to this as the Gove Member of the Littleton, and Billings (1956) shows it as the Gove Member of the Berwick.

Contacts. The Berwick Formation is inferred to overlie conformably the Eliot Formation, although, as noted above, the contact is nowhere exposed. Between Rochester, New Hampshire, and North Berwick, Maine, the Berwick is in contact with the Gonic Formation. Although not exposed, the contact has been narrowed down to a 3 m zone covered by glacial drift on the southeast edge of Windy Hill in the Berwick 15' quadrangle. Here, the schistosities of both Formations are parallel and the rocks are unsheared, thereby suggesting conformability. The Gonic is assumed to overlie the Berwick.

Thickness. The thickness of the Berwick Formation is estimated to be between 1800 and 2400 m (Hussey, 1968, p. 295).

Gonic Formation

Name and Reference Locality. The Gonic Formation for exposures on the southeast side of Chesley Hill northwest of the village of West Gonic, New Hampshire. These exposures and the exposures along Estes Brook for a distance of 1 km upstream of Turkey Street in the northwestern part of North Berwick (NE 9th, Somersworth 7 1/2' quadrangle), are designated as the reference localities for the Gonic Formation.

Distribution. The Gonic Formation is exposed in a single belt 2.5 km wide extending from the south end of the Lyman Pluton near Bauneg Beg Pond in North Berwick southwest through Gonic, New Hampshire, to the town of Great Barrington a distance of approximately 30 km. The outcrop belt of the Formation coincides in Maine with a line of low hills (Pine Hill, Diamond Hill, Beech ridge, and the south portion of Windy Hill) indicating that the Formation is more resistant to erosion than the surrounding Berwick and Rindgemere Formations.

Lithology. Two lithologies dominate the Gonic Formation:

1) medium-gray silvery muscovite schist with prominant porphyroblasts of staurolite, garnet, biotite, and retrograde chlorite; and

2) medium-gray slightly muscovitic and biotitic quartzite and quartz mica schist with very minor feldspar. Bedding is uncommon, and when present is thin and non-persistent.

Contacts. The Berwick-Gonic contact, already discussed, is inferred to be conformable. The contact with the Rindgemere Formation is not exposed but is inferred to be an extension of the Nonesuch River-Campbell Hill Fault. These faults and their bearing on the Gonic-Rindgemere contact will be discussed more fully below under "Structure".

Thickness. The rarity of bedding and the virtual lack of information on the deformation of the Gonic formation makes an estimate of thickness uncertain. Katz (1917) suggested 150 m. This may be low and the writer suggests the Gonic may be as much as 300 m thick.

Vassalboro Formation

Name and Reference Locality. The Vassalboro Formation was named by Perkins and Smith (1925) for exposures in the town of Vassalboro to the north of the study area. It has been traced by Osberg (1968, 1980) and Newberg (1981a, b) into the study area. The exposures along Interstate Highway I-95 between Brunswick and Freeport, and in the large road metal quarry in the north side of Maine Highway 25 just west of Gorham Village are collectively designated as the reference localities for the Vassalboro Formation in the study area..

Distribution. The Vassalboro Formation occupies a 2-7 km wide tract extending from the north edge of the map southward between the Sebago Batholith on the northwest and the Casco Bay Group boundary fault, and the parts of the Flying Point and Nonesuch River Faults on the southeast. The Formation also occupies the roughly triangular area between Westbrook, North Baldwin, and Hollis where the Windham Formation is infolded with it. This latter area was originally mapped as the Berwick Formation by the writer and Gilman (personal communication). The use of the name Vassalboro for the rocks of these two belts is here proposed because 1) the Vassalboro formation is traceable directly into the Brunswick-Portland area from the type locality of the Vassalboro Formation, and 2) the rocks assigned to the Vassalboro Formation the Westbrook-North Baldwin-Hollis area are in stratigraphic sequence below the Windham Formation which is correlated with the Waterville Formation indicating that there is a stratigraphic unity between these Formations and those of the Waterville area.

Lithology. In the Gorham-Bonny Eagle-Hollis area the Vassalboro Formation consists of thin to medium (2-30 cm) bedded, fine to medium grained, medium gray non-salt-and pepper textured quartz-plagioclase-biotite-hornblende granofels and slightly schistose granofels, with thin interbeds of buff-weathering medium greenish gray calc-silicate granofels. Included are rare thin interbeds of biotite-muscovite-quartz-staurolite or sillimanite schist, and an occasional 2-5 m thick slightly schistose quartz-plagioclase-biotite-hornblende granofels. Graded bedding is locally present but not as common as in the Kittery Formation to the south or in the low metamorphic grade Vassalboro in the Waterville area.

The Vassalboro of the Brunswick-Portland area consists of thin bedded to massive salt and pepper-textured fine to medium grained medium gray quartz-plagioclase-biotite-hornblende gneiss locally lit-per-lit injected by foliated pegmatite stringers commonly 15 cm to 2 m thick. Calc-silicate gneiss occurs as thin interbeds but is not as common as in the other belt. Rare interbeds of metapelite with sillimanite, and one 2 to 5 m zone of calc-silicate marble have been observed in the Freeport area. Zones of rusty granofels 3 to 6 m thick are present sporadically throughout this belt.

Hussey (1971a) mapped a lens of chalky-weathering plagioclase-quartz-biotite granofels interpreted to be a metafelsic volcanic member of the Berwick Formation, but now assigned to the Vassalboro. This lens, 0.7 km wide, extends from South Gorham 10 km to the southeast where it terminates against the Nonesuch River Fault.

Contacts. In the Windham area, the Windham Formation conformably overlies the Vassalboro, the contact being exposed at three places (see discussion under the Windham Formation). Between Hollis and North Baldwin, the Vassalboro is bounded by the Rindgemere Formation on the west. The Vassalboro-Ridgemere contact is inferred to be a premetamorphic folded fault. Between Portland and the north edge of the map, the Vassalboro is bounded on the east by members of Cushing Formation across another inferred premetamorphic folded fault. Finally, form North Scarboro to North Saco, the Vassalboro is separated from the Cape Elizabeth Formation by the Nonesuch River Fault.

Thickness. The thickness of the Vassalboro Formation cannot be accurately estimated due to uncertainty as to the repetition by recumbent and upright folding. It is probably on the order of 1500 to 2000 m.

Windham Formation (new name)

Name and Reference Locality. Hussey (1971a) used the name "Windham Formation" for pelitic, psammitic, and calcareous metasediments exposed in the Windham area. These rocks were first mapped by Pendexter (1949) who referred to them as the Little River Formation; however, this name has been formally used for rocks in the Eastport-Cutler area (Gates, 1961), and therefore cannot be used for these metamorphic rocks. The name is for the town of Windham where the formation crops out extensively. The exposure beginning at the foot of the dam at the south end of Dundee Pond near North Gorham, and extending 250 m south along the Presumscot River; and the exposures along U.S. Highway 202 and Maine Highway 115 in Windham, are designated as reference localities for the Windham Formation.

Distribution. The Windham Formation is restricted to 3 northeast-trending belts: a 2 km wide belt occupying a doubly plunging synform between the north end of the Lyman Pluton and Windham Center; a synformal belt up to 3 km wide extending 20 km southeast from the Sebago Pluton at West Gray; and a synformal belt 2 km wide and 20 km long between Bonny Eagle in the northern part of Hollis, and the Sebago Batholith at North Windham.

Lithology. The principal lithology of the Windham formation is thin-bedded to massive rusty and non-rusty weathering muscovite-biotite-garnet-quartz schist with kyanite and staurolite, or sillimanite depending on metamorphic grade. Interbedded with this metapelite are thin beds of quartz-biotite±muscovite granofels and granulose schist, and occasionally calc-silicate gneiss.

Stratigraphically near the middle of the Windham is a metalimestone member consisting of gray thin ribbony bedded metalimestone and calc-silicate marble with interbedded quartz-plagioclase-biotite±hornblende schistose granofels. In addition to occurring as interbeds in the metalimestone, the latter lithology with thin calc-silicate interbeds (closely resembling the Berwick Formation) forms thin zones between the metapelite and metalimestone.

The Windham Formation has not been migmitized.

Contacts. The Windham-Vassalboro contact is exposed at the following localities:

1) on the north side of Maine Route 25, 2.3 km west of Standish;

2) along a tributary to the North Branch Little River, 0.25 km S 12 E of BM153 in the northwest corner of the Portland 15' quadrangle; and

3) along Douglas Brook 1.91 km S 19 E of the same bench mark. At each locality the contact is conformable but no primary sedimentary structures are present to indicate topping sense.

The lower contact of the metalimestone member with pelite of the Windham is exposed along U.S. Highway 202 at the second of the two reference localities noted above. One meter below (and to the northwest of) the contact is a 5 cm graded bed with a southeast facing direction; 260 m south along the highway is the contact with pelite southeast of the metalimestone. Approximately 1.2 m into the pelite is a crudely graded bed facing northwest (D. W. Newberg, pers. comm.). These relations suggest that the metalimestone is here preserved in the nose of a small south-plunging syncline. This is a critical locality for interpreting regional stratigraphic sequence in that it places the Windham Formation stratigraphically above the Vassalboro Formation.

Thickness. The thickness of exposed Windham (including the central metalimestone member) is estimated to be 600 m and the ribbon metalimestone, about 60 m (Hussey, 1971b).

Bucksport Formation

Name and Reference Locality. The name Bucksport Formation was first used informally by J. M. Trefethen in a privately prepared map produced to the 1950 New England Intercollegiate Geological Conference in Maine. Wing (1958) first used the name formally in print. The formation is named for exposures in the Silver Lake area of the Town of Bucksport. The reference locality for the Bucksport Formation in the Bath 1x2° map sheet is the shoreline exposures at Ocean Point on Linekin Island in East Boothbay.

Distribution. The Bucksport Formation is exposed in a general belt 18 km wide between Pemaquid Point on the east and Edgecomb on the West northward to the edge of the map sheet, beyond which it is directly traceable to the type area in Bucksport.

Lithology. The Bucksport is lithically similar to the Vassalboro, Kittery and Berwick Formations. It consists of:

1) thin bedded (2 to 30 cm) medium gray fine to medium grained quartz-plagioclase-bioite-hornblende granofels and evenly foliate gneiss, and greenish gray calc-silicate granofels and gneiss with hornblende and diopside;

2) somewhat rusty weathering quartz-plagioclase-biotite-hornblende schistose gneiss and granofels; and

3) poorly thin bedded to massive medium gray salt-and-pepper-textured quartz-plagioclase-biotite-hornblende granofels and gneiss with minor thin beds of calc-silicate gneiss. The rusty granofels occurs as zones 1-3 m wide principally in the thin-bedded calc-silicate rich zones (lithology 1 above).

Contacts. In the Boothbay-Edgecomb area, the Bucksport is overlain structurally by subpelitic and pelitic schist and sillimanite-bearing migmatite correlated with the Cape Elizabeth Formation (Hussey, work in progress). The contact is exposed at several localities along the shore, and although the Bucksport and Cape Elizabeth formations appear to be concordant across it, the contact is interpreted to be a premetamorphic folded fault because of inferred differences in ages of the two formations. The Bucksport structurally overlies the Cross River Formation, the contact probably being either an angular unconformity, or a premetamorphic folded fault.

Thickness. Estimates of the thickness of the Bucksport Formation are difficult to make because of the extensive folding of the Formation. The total thickness in the Boothbay area probably does not exceed 1000 m.

Rock Units of the Friendship-Tenants Harbor Area

East of the Waldoboro Pluton (Plate II) Newberg, 1976, and Guidotti (1979) and Hussey (1972) have mapped in reconnaissance and local detail, the continuation of units of the Benner Hill Sequence mapped and described by Osberg and Guidotti (1974) in the Camden-Rockland area to the north. None of these units have been formally described and named to date.

The lowest unit of the Benner Hill Sequence is informally referred to by Osberg and Guidotti (1974) as the "quartz-rib schist unit". It consists of feldspathic quartzite and gray mica schist interbedded on a 1/4 to 1 cm scale. Flaggy-bedded amphibolites occur sporadically within this lithology. In the Friendship 7 1/2' quadrangle, Newberg (1979) notes that the unit includes an 80 m thickness of calc-silicate granofels at the top.

Above the "quartz-rib schist unit" is the "biotite quartzite and schist unit" which according to Guidotti (1979) is a heterogeneous unit consisting of numerous biotitic rock types; quartzites, granulites, grits, quartzose pelites, and quartz-pebble conglomerates are the most common. All are gray weathering. Bedding varies from thin to 3 m. Muscovite pseudomorphs after andalusite occur commonly in the pelites. Calc-silicate lenses and boudined beds with grossularite and diopside occur sparingly throughout the area mapped by Newberg (1979) in the Friendship quadrangle.

Above this unit in the Tenants Harbor-Port Clyde area is the Benner Hill unit (Guidotti, 1979) consisting of thinly-interbedded rusty-weathering quartz-mica schist and quartzite with characteristic thin brownish red bedlets rich in garnet. This is identical to the lithologic variety of the Benner Hill unit of Osberg and Guidotti (1974) shown on their map as unit 3A. Guidotti (1979) notes that lithology typical of unit 3B (rusty-weathering pelitic schist, informally referred to as "Prison Farm lithology") of Osberg and Guidotti (1974) is interbedded with the above on a small scale as at Southern Island at the outlet of Tenants Harbor.

In the Friendship area, the Benner Hill unit is represented by very rusty-weathering interbedded metasandstone and graphitic, sulfidic metapelite (Prison-Farm type Benner Hill). Within these metasediments are concordant amphibolite layers 1-6 m thick in which textural variations suggest relict chill margins at the contacts with the metasediments, thus suggesting the possibility that they are premetamorphic sills (Hussey, 1972). Alternatively they may be interbedded flows or ash beds. This belt of Benner Hill unit occupies the core of a syncline mapped by Newberg (1979) to the north in the Waldoboro East quadrangle.

West of the Benner Hill unit outcrop belt (west of Meduncook River) in the Friendship quadrangle, Hussey (1972) and Newberg (1976) have mapped a thick sequence of amphibolite and associated light gray feldspathic metatuff, impure marble and calc-silicate. In places the amphibolite preserves relict pillow structure with vesicular structure in the core of pillows. This basic volcanic sequence in not repeated on the east limb of the syncline but on the northeast tip and southeast side of Friendship Long Island it appears to interfinger with Prison-Farm type rusty schist and gneiss of the Benner Hill unit. Guidotti (1979) notes that amphibolites, some possibly with pillow structure, are interbedded with garnet-bedlet type Benner Hill near Deep cove on the east side of the St. George River. These may correlate with the more abundant amphibolites on the west side of Meduncook River. The greater amount of metavolcanics of the latter area may represent a volcanic eruptive center.

Locally between the amphibolite belt and the South Pond Porphyritic granite, is a narrow zone (up to 300 m wide) of quartz-feldspar-biotite-muscovite gneiss with minor sillimanite (Hussey, 1972). This unit may be equivalent to the nonrusty "biotite quartzite and schist unit" but in part may be a highly foliated, possibly sheared, phase of the South Pond porphyritic granite.

On Metinic Island Guidotti (1979) has mapped a sequence of rusty-weathering rocks consisting mostly of thick-bedded dark biotite quartzite, schist, and granulite, and minor rusty-weathering metapelite with coarse chiastolites (up to 2 cm in diameter). These are cut by sills and dikes of metamorphosed diorite and gabbro. He assigns these rocks to the Owls Head unit of the Megunticook sequence of Osberg and Guidotti (1974).

Rocks similar to those of Metinic Island have been examined briefly on Matinicus Island. The western half of the island consists of a heterogeneous assemblage of generally dark-colored quartzite, quartz-biotite schist, amphibolite, light gray chalky-weathering metafelsite, and rusty-weathering dark gray quartzite and quartzose schist. These rocks are in contact with a medium-grained biotite granite which comprises the eastern half of the island and all of Criehaven Island nearby.

In the Rockland 7 1/2' quadrangle, Guidotti discovered contorted brachiopods in a quartzite within garnet-bedlet type Benner Hill. Boucot (et al.) (1979) assign a Caradoc (Middle-Late Ordovician) age to these brachiopods, and this serves as the basis of assigning a middle to late Ordovician age for the entire Benner Hill Sequence (Osberg and Guidotti, 1974).

SHAPLEIGH GROUP

Introduction

The name "Shapleigh Group" was proposed by Hussey (1968, p. 290) for the thick sequence of metapelitic rocks of the Gonic, Ridgemere, and Towow Formations. The name is taken from the town of Shapleigh in northern York County.

In adjacent New Hampshire rocks of the Shapleigh Group were previously mapped as the Littleton Formation (Billings, 1956, Freedman, 1950). Recent work in southeastern New Hampshire (Eusden, et al., 1984; Eusden, 1984) and southwestern Maine (Hussey, 1984) suggests that these rocks may be either 1) equivalent to the Rangeley-Carrabassett sequence of Moench (1971) in the Rangeley-Phillips area, or 2) equivalent to the Rangeley-Seboomook sequence of Boone (1973) and Pankiwskyj (1979) in the Little Bigelow-Kingfield area. Work of Eusden (1984) in the Rochester, New Hampshire, South Lebanon, Maine area has resulted in a revision of the map units of the western part of the Berwick 15' quadrangle. Plate I shows my reinterpretation of Eusden's mapping. All workers agree that the name Littleton should be dropped for these rocks inasmuch as the Littleton Formation in Western New Hampshire crops out in a zone several structural belts west of strike of the Shapleigh Group, whereas the rocks of the Rangley-Phillips-Little Bigelow-Kingfield area, and the Shapleigh Group both lie within the Kearsarge-Central Maine Synclinorium (Lyons, et al., 1982).

The stratigraphic status of the Gonic formation is uncertain. Although the writer included it in the Shapleigh Group on the grounds of its general pelitic nature (Hussey, 1968), it now appears that it may be associated with the Berwick Formation and be equivalent to the Gove Member of the Berwick described by Freedman (1950) in the Mt. Pawtuckaway quadrangle, New Hampshire. In this report, its description is included with the Merrimack Group. Furthermore it is separated from the Ridgemere Formation by the inferred extension of the Nonesuch River Fault. However, if further work should show that this contact is a conformable sedimentary one and not a fault, then it would be proper to retain the Formation as the basal part of the Shapleigh Group.

The Shapleigh Group as now reinterpreted includes, in inferred ascending stratigraphic order, the Lower and Upper Members of the Rindgemere Formation, the Towow Formation and an as yet unnamed unit above the Towow in the Flatrock Bridge area of Lebanon along the Maine-New Hampshire state line.

In New Hampshire, equivalents of Lower and Upper Members of the Rindgemere were mapped as Pittsfield and Jenness Ponds Members respectively, of the Littleton Formation (Stewart, 1961)

A discontinuous rusty unit mapped by Eusden (1984) as part of his unit 3, which he correlates with the Towow Formation, I reinterpret to be a separate unit stratigraphically between the Upper and Lower Members of the Rindgemere.

This is not given formal member status in this report, but is included as an unnamed subunit of the Lower Rindgemere. Eusden (1984) also maps a thin discontinuous quartz-feldspar-biotite and calc-silicate granofels unit (his unit 4A) which I include as thin discontinuous lenses within the Upper Rindgemere. Eusden's Unit 1 and Unit 2 are included as part of the Lower Rindgemere. His unit 3 in part equates with the Towow, but in part is another unit between the Upper and Lower Rindgemere as noted above. His Unit 4 is part of the Upper Rindgemere except that surrounded by, and stratigraphically on top of the Towow.

Rindgemere Formation

Name. The Rindgemere Formation was mapped and named by Katz (1917) from exposures in the Salmon Falls River at the former Rindgemere railroad station (a name no longer appearing on topographic maps) in East Rochester 175 m upstream from the U.S. 202 highway bridge across the River. Hussey (1968) divided the formation into two distinctive members, referred to informally as "lower part" and "upper part". The lower part is here designated the Lower Member and the upper part, the Upper Member.

Lower Member

Reference Locality. The Lower Member crops out typically on Bauneg Beg Mountain in the town of North Berwick (Berwick 15' quadrangle, EC 9th, 5.3-6.5 km, S 7 W of the junction of U.S. Highway 202 and Maine Highway 109 in the center of the town of Sanford. This is designated the reference locality for the general lithology of the Member.

Distribution. The Lower Member of the Rindgemere Formation crops out in a belt varying in width from 3 km in the Berwick area to 16+ km in the Kezar Falls area. This belt extends from the edge of the Sebago Batholith in Brownfield southward into New Hampshire. The Lower Member is thus the most areally extensive metasedimentary unit in the Portland-Bath map area.

Lithology. The Lower Member typically is a sequence of variably bedded metamorphosed pelitic shale and argillaceous sandstone, with minor rusty-weathering pelite and non-rusty calcareous sediments. In the southern and central parts of the outcrop belt between Berwick and North Berwick, the rocks are non-to slightly migmatized non-to slightly rusty-weathering medium gray muscovite-biotite-garnet-quartz schist, biotite-muscovite-sillimanite-garnet±staurolite-quartz schist, and biotite-quartz±muscovite schist. Interbedded with these metapelitic lithologies are 5-20 cm beds of schistose biotite±muscovite quartzite. Fine-grained reddish structurally contorted coticule (garnet-quartz-biotite) beds 2-6 cm thick occur frequently in the upper part of the section and Eusden (1984) has mapped this as a separate unit (his unit #2). Muscovite pseudomorphs up to 20 cm in length are common in the metapelite. Staurolite most frequently occurs as small porphyroblasts within these pseudomorphs, but also occurs as idioblastic porphyroblasts in the matrix. Sillimanite occurs in fibrolitic clots intergrown in biotite. Migmatized metapelite mapped by Eusden (1984) northwest of the coticule-bearing unit is here included with the Lower Ridgemere.

In the Kezar Falls and Newfield areas in the northern part of the outcrop belt Gilman (1977) reports the following lithologies:

1) moderately to intensively migmatized reddish brown to gray biotite-muscovite-sillimanite-garnet schist;

2) thin-bedded brownish gray fine to medium grained biotite-muscovite-quartz-sillimanite schist with interbedded thin psammitic layers;

3) sulfidic rusty-weathering light gray (fresh) quartz-plagioclase-muscovite schist;

4) fine-grained gray sub-salt-and-pepper-appearing quartz-plagioclase-biotite schist and granofels; and

5) calc-silicate granofels and gneiss with minor marble with diopside, grossularite, vesuvianite, and light green amphibole. The vesuvianite and grossularite-bearing rocks are usually coarse grained with a skarn-like texture.

The calc-silicate and marble occur in irregular, apparently discontinuous belts in the Sanford-Newfield area but are absent in the Lebanon, North Berwick and Berwick parts of the Lower Member outcrop belt, as well as the northern 2/3 of the belt in the Kezar Falls 15' quadrangle. The biotite granofels is usually closely associated with the calc-silicate. Rusty schist is mapped by Gilman (1977) in two belts within the Kezar Falls quadrangle, the larger one approximately 3 km wide extending from Sawyer Mountain in Limerick to Mount Cutler in Hiram and the smaller one just northwest of Pequawket Lake. the apparently discontinuous calc-silicate and marble belts may represent a single stratigraphic sub-member of the Lower Member.

Between Bauneg Beg Mountain and Beech Ridge in North Berwick, the writer has mapped a minor unit of slightly rusty-weathering light gray muscovite-biotite-quartz schist in a 200 to 300 m wide crescentic belt approximately 2 km long.

Locally at the contact between the Lower and Upper Members of the Rindgemere is a relatively thin (up to 300 m) sequence of poorly-bedded to massive strongly schistose and crenulated rusty-weathering sulfidic muscovite-biotite-quartz schist with minor chlorite, staurolite, garnet, sericitized andalusite and sillimanite (Eusden, 1984). Interbedded with the schist, particularly in the lower part of the section, is quartz-muscovite-biotite schist representing sandy interbeds. On fresh surfaces this rusty unit is a light-colored schist in contrast to the dark gray graphitic schist typical of the Towow Formation. For this reason I do not favor a correlation of the two units. In New Hampshire, this unit crops out in two belts, one extending west-southwestward from Rochester, New Hampshire, approximately 6 km, and the other extending from Parker Mountain in Strafford north-northeast to West Lebanon, Maine. In Maine it is present in an irregular belt south of Mousam Lake in Shapleigh, and just east of Milton Mills, New Hampshire (see Plate I). Reference locality for this unit is the exposure along the Saulding Turnpike, New Hampshire, 4.6 km south of exit 17 (Milton Exchange). This is stop 3 of Eusden et al. (1984). Here the contact with the structurally overlying non-rusty part of the Lower Rindgemere is exposed, and graded beds at the contact indicate that the non-rusty Lower Rindgemere is older that the rusty unit, the section thus being upside down (Eusden et al., 1984).

Contacts. The contact with the underlying Gonic Formation is the inferred Nonesuch River Fault, a major post metamorphic fault. The contact with the Upper Member, exposed on the Spaulding Turnpike as above noted, is conformable. In the Baldwin-Waterboro area the Lower Rindgemere-Vassalboro contact is inferred to be a folded premetamorphic fault on the basis of correlation of the Lower Rindgemere with the Sangerville Formation of the Central Maine Sequence.

Thickness. The thickness of the Lower Member is estimated to be between 1500 and 2400 m. Calc-silicate and marble bands, although quite variable in width of outcrop probably do not exceed 100 m in thickness.

Upper Member

Reference Locality. Extensive exposures of the Upper Member are rare, and the following three accessible localities where typical aspects of the Member can be seen are designated as the reference localities:

1) stream exposures in the channel of Little River 2.65 km S 30 from the junction of U.S. Highway 202 and Depot and Little River Roads at East Lebanon;

2) exposures on the west side of Little River Road 5.10 km S 20 E of the same junction; and river bank outcrops on the southwestern shore of the Salmon falls River .45 km down stream from the U.S. Highway 202 bridge at East Rochester.

Distribution. The Upper Member is exposed in a belt extending from Acton, Maine, south southwest to the Maine-New Hampshire border in south Lebanon and from there westward into New Hampshire. The belt is interrupted centrally by the Towow Formation in the core of the Lebanon Antiform. The Upper Member averages 5 km in width on the southeast side of the Towow Formation and 2-3 km wide northwest.

Lithology. The Upper Member of the Ridgemere Formation is a rhythmically-bedded generally thin to medium and occasionally massive metamorphosed pelite, argillaceous sandstone, and granule bearing argillaceous sandstone metamorphosed to andalusite-staurolilte and sillimanite-staurolite grades. The following lithologies are typical of this Member:

1) 10 to 50 cm graded beds of quartz-biotite-plagioclase granofels, occasionally with quartz granules at the base, passing upward into muscovite-biotite-quartz schist with 1 to 8 cm long pseudomorphs of muscovite after chiastolite. Staurolite occurs as small porphroblasts in the muscovite pseudomorphs. The quartz granules are commonly pale blue in color. The psammite to pelite ratio is approximately 70 to 30. In New Hampshire approximately 2 km north of Rochester fresh pink chiastolite is present.

2) Non-graded 1 to 25 cm beds of alternating quartz-biotite-muscovite schist and muscovite-biotite-quartz±staurolite pseudoandalusite schist.

3) Evenly rhythmic 10 to 15 cm interbedded commonly slightly rusty-weathering weakly bedded muscovite-biotite-quartz-staurolite schist and quartz-biotite-muscovite schist.

In the East Rochester area where fresh andalusite is present, the metapelite is medium dark gray in color, somewhat carbonaceous and phyllitic in texture. In the Lebanon-Acton area where the metamorphic grade is somewhat higher, the metapelite is medium silvery gray.

Eusden (1984) maps a thin discontinuous metasandstone unit (his Unit 4A) consisting of light gray massive to thinly laminated quartz-plagioclase-biotite-amphibole granofels with calc-silicate pods up to 20 cm long. The reference exposure for this litholgy is the riverside outcrop on the west bank of the Salmon Falls River in the East Rochester, New Hampshire, just upstream from the U.S. Highway 202 bridge.

Nowhere is the Upper member migmatized.

Contacts. The contact with the rusty schist assigned to the Lower Member of the Rindgemere, exposed along the Spaulding Turnpike as noted above is conformable. The contact with the overlying Towow is not exposed but is probably conformable.

Thickness. The thickness of the Upper Member is estimated to be approximately 300 m.

Towow Formation

Name and Reference Locality. Katz (1917) derived the name from the original name of the first settlement in the Town of Lebanon, Maine, where the Formation principally crops out. Outcrops of the Formation are very poor, and the several exposures along U.S. Highway 202 for approximately 4 km northeast from Blaisdell Corners (Berwick 15' quadrangle) are designated as reference localities for the general Towow lithology. The reference locality for the basal grit member is a roadside outcrop on Merchants Row 1.42 km N 44 W of its intersection with Upper Guinea Road in Lebanon (WC 9th, Berwick 15' quadrangle).

Distribution. The Towow Formation crops out in a northeasterly-trending belt 18 km long and 3-5 km wide in the Town of Lebanon, and probably extends less than a kilometer into Rochester, New Hampshire. The Towow Formation also crops out in the area of Jenness and Wild Goose Ponds in the western edge of the Alton, New Hampshire 15' quadrangle (Hussey, reconnaissance mapping, 1976).

Lithology. The Towow is a sequence of very rusty weathering pyrrhotitic muscovite-quartz schist (light gray and silver on fresh surface, and thus similar to some of the Upper Rindgemere lithologies) and dark gray graphitic muscovitic phyllite. At the base of the rusty phyllites is a thin but conspicuous mapped unit of slightly rusty weathering micaceous quartz granule mataconglomerate. Quartz grains, some bluish in color and up to 6 mm in diameter are abundant in a variable quartzose to dark muscovite-graphite phyllite matrix. This lithology, apparently at the base of rusty phyllite is present in the Jenness-Wild Goose Ponds area in New Hampshire and was mentioned by Stewart (1961, p. 14).

Contacts. The Towow Formation is believed to be conformable with the underlying Upper Member of the Ridgemere. The granule metaconglomerate at the base of the Formation is probably a feature of sedimentation and not erosion of the Ridgemere; it does not represent an unconformity. The contact with the overlying unnamed unit is exposed near Flatrock Bridge on the Salmon Falls River (Eusden et al., 1984, Stop 6). It is conformable and sharp and graded beds in the overlying unit unequivocally establish the sequence.

Thickness. The rusty schist and phyllite of the Towow probably do not exceed 150 m, and the granule metaconglomerate varies from 0 to an estimated 40 m.

Unnamed Unit Above the Towow Formation

Near Flatrock Bridge on the Maine New Hampshire border approximately 3 km upstream from East Rochester, New Hampshire, Eusden et al., (1984, Stop 4), demonstrate that the Towow Formation is succeeded upward by non-rusty rhythmically bedded metasandstone with thin metapelite tops of graded beds. The stratigraphic succession is clearly indicated by graded bedding at the contact with the underlying Towow. The writer interprets this unit to be preserved in the core of the inverted Lebanon Antiform in a belt 0.5 km wide and 3 km long.

CORRELATIONS AND AGES OF THE STRATIFIED ROCKS

General Statement

The ages of the stratigraphic units of the Portland and Bath sheets are difficult to place in the relative time scale. No fossil localities are known in the map area; the closest localities outside the map area include Rockland, where highly deformed brachipods of Middle Ordovician (Caradoc) age occur in the Benner Hill Sequence (Osberg and Guidotti, 1974; Boucot, et al., 1972); the Waterville area where Silurian age graptlites have been recovered from the Waterville and Mayflower Hill formations (Osberg, 1968); and the Newburyport, Mass., area where Late Silurian to Early Devonian age ostracodes occur in unmetamorphosed sediments interbedded with the Newbury Volcanics (Shride, 1976). Correlations of the stratigraphic units of the map area to these fossiliferous localities are fraught with difficulties including the presence of numerous faults and plutons which interrupt the continuity of the stratigraphic units, and the possibility that similar lithologies of markedly different age either occur in different parts of the stratigraphic column or have been brought together from geographically separate areas by plate tectonic movements. The few radiometric ages that have been obtained for stratigraphic units may reflect more the time of metamorphism or age of provenance than age of deposition or eruption. Radiometric dates bearing on the chronologic interpretation in the study are given in Table I.

TABLE I. ISOTOPIC AGES BEARING ON THE INTERPRETATION OF CHRONOLOGY IN THE PORTLAND-BATH 2° SHEETS

ROCK UNIT	REFERENCE ON FIGURE	METHOD	INTRUSIVE INTO	AGE MA	REFERENCE
Exeter Pluton		Rb/Sr W	Kittery, Eliot	473±37	Gaudette, et al., (1984)
Diorite, Isles of Shoals		Rb/Sr W	Rye	477	Gaudette, et al., (1984)
Newburyport Quartz Diorite		$^{207}Pb/^{206}Pb$ Zircon	Kittery	450±15	Zartman & Naylor, (1984)
Chelmsford Granite			Merrimack Group	389±5	Zartman & Naylor, (1984)
Ayer Granite			Merrimack Group	433±5	Zartman & Naylor, (1984)
Berwick Formation				1237	Aleinikoff, (1979)
Hallowell Granite		Rb/Sr W	Vassalboro, Waterville	387±11	Dallmeyer & Van Breeman, (1981)
Togus Quartz Monzonite		Rb/Sr W	Vassalboro, Waterville	394±8	Dallmeyer & Van Breeman, (1981)
Cushing Formation		Rb/Sr W		481±40	Brookins & Hussey, (1978)
Cape Elizabeth Formation		Rb/Sr W		485±30	Brookins & Hussey, (1978)
Massabesic Orthogneiss		U/Pb Zr	Massabesic Paragneiss	475±48	Aleinikoff et al., (1979)
Massabesic Paragneiss				646	Aleinikoff et al., (1979)

TABLE I. ISOTOPIC AGES BEARING ON THE INTERPRETATION OF CHRONOLOGY IN THE PORTLAND-BATH 2° SHEETS (CONTINUED)

ROCK UNIT	REFERENCE ON FIGURE	METHOD	INTRUSIVE INTO	AGE MA	REFERENCE
Cushing Formation		Rb/Sr		494±25	Gaudette, (1983)
Webhannet Pluton		Rb/Sr W	Kittery, Eliot, Berwick	390±10	Gaudette et al., (1982)
Webhannet Pluton		Zr Pb	Kittery, Eliot, Berwick	403±13	Gaudette et al., (1982)
Lyman Pluton		Rb/Sr W	Vassalboro, Rindgemere, Berwick	322±12	Gaudette et al., (1982)
Biddeford Pluton		Rb/Sr W	Berwick, Kittery	344±12	Guadette et al., (1982)
Sebago Batholith		U/Pb Zr	Vassalboro, Windham, Rindgemere, Sangerville, Waterville	325±3	Aleinikoff, (1984.)
Concordant pegmatites		Rb/Sr W	Vassalboro, Cushing	375-385	Brookins and Hussey, (1978)
Discordant pegmatites		Rb/Sr W	Vassalboro, Cushing	375-385	Brookins and Hussey, (1978)
Saco Pluton		Rb/Sr	Vassalboro, Cape Elizabeth, Berwick	307±20	Gaudette, et al., (1982)
Three Mile Pond Stock		Rb/Sr	Vassalboro, Waterville	381±14	Dallmeyer & Van Breeman, (1981)

Rye Formation

The age of the Rye Formation is uncertain due to lack of documentation by fossils, or unequivocal correlations with clearly dated formations. Billings (1956) and Novotny (1969) suggest a correlation with the Ammonoosuc Volcanics and the Albee Formation of Ordovician (?) age in west-central New Hampshire. Such a correlation is now regarded as questionable due to the absence of volcanics in the Rye Formation and the likelihood that the Rye and the Albee-Ammonoosuc sequence represent distinctly different tectono-stratigraphic packages. I favor a correlation of the Rye Formation with the following: Nashoba Formation, Fishbrook Gneiss and Shawsheen Gneiss of northeastern Massachusetts (Bell and Alvord, 1976); the pelitic phases of the Massabesic Gneiss in New Hampshire (Bothner, et al., 1984); The Cape Elizabeth Formation of the Casco Bay Group and possibly the Ellsworth Formation (in part) of eastern Maine. Olszewski (1979) reports 207Pb/206Pb age on zircons from the Fishbrook and Shawsheen Gneisses and the Nashoba Formation of 742 $\pm$ 91 Ma. The age of the Rye, thus, is tentatively Late Precambrian.

Cross River Formation

The Cross River Formation has no clear-cut correlatives. The upper granofels member has some lithic similarity to the Richmond Corner Member of the Cushing. The lower rusty member closely resembles the Torrey Hill Member of the Cushing. The closest exposures of these Members are 60-70 km west of the Cross River exposures. The seemingly greater degree of deformation of the Cross River, in particular the upper granofels, as compared to that of the Bucksport Formation may indicated that either the Cross River Formation was subjected to an orogeny prior to Bucksport deposition or the lithology of the Cross River reacts more sensitively to deformation that the Bucksport. The Cross River may correlate with the Passagassawaukeag Gneiss package of the Belfast area (Bickel, 1976) for which Steart and Wones (1974) suggest a late precambrian to early Ordovician age. The age of the Cross River is thus tentatively assigned to the age range Late Precambrian to Early Ordovician.

Cushing Formation

The Cushing Formation is correlated with the more felsic portions of the paragneiss of the Massabesic Gneiss Complex. In particular, the Mount Ararat Member of the Cushing is strikingly similar to that part of the Massabesic Gneiss exposed at Stop 7 of Bothner et al. (1984) near Manchester, New Hampshire. The Cushing is tentatively correlated with felsic parts of the Ellsworth Formation in eastern Maine, and the Coldbrook Volcanics of southern New Brunswick. Brookins and Hussey (1978) report an Rb/Sr whole rock age of 481 $\pm$ 10 Ma for the Formation. Brookins interprets this to be the time of volcanic activity when the rocks were first erupted. Lyons, et al. (1982) feel that such ages reflect time of metamorphism, and consequently the age of the Cushing would be no younger than Cambro-Ordovician, and might be Precambrian.

Cape Elizabeth Formation

The Cape Elizabeth Formation can be traced into the Hogback Schist of Perkins and Smith (1925) in the Belfast-Liberty area to the north of the map area. It may also correlate with the non-rusty quartz-mica schist units of the Benner Hill Sequence mapped by Osberg and Guidotti (1974) in the St. George River estuary near Rockland, an maybe with parts of the Ellsworth Schist in the Ellsworth-Blue Hill area. Finally, it may equate with the Rye and Nashoba Formations and parts of the Massabesic Gneiss on the basis of gross lithic similarity. Brookins and Hussey (1978) report a Rb/Sr whole rock age of 485 $\pm$ 30 Ma for the Cape Elizabeth Formation; if this is a metamorphism age, the Cape Elizabeth Formation, like the Cushing, may be of Late Precambrian to Early Ordovician age. If it is equivalent to the "rib schist" and "biotite quartzite and schist" units of the Benner Hill Sequence, it is of Middle to Late Ordovician age based on Caradocian age brachiopods in a quartzite lens within the overlying Benner Hill unit of the Benner Hill sequence (Boucot et al., 1972).

Upper Casco Bay Group Units

The Spring Point, Diamond Island, Scarboro, Spurwink, Jewell, and Macworth Formations are present only in the Casco bay area (Hussey, 1971a, b; 1968), and in part in the Liberty area (Pankiwskyj, 1976). They have no known lithic correlatives elsewhere in the general area. Because they form a conformable sequence with the Cape Elizabeth Formation, the writer regards them to be of the same age range as the Cape Elizabeth Formation, i.e., Late Precambrian to Early Ordovician.

Windham Formation

The Windham formation is correlated with the Waterville Formation of Central Maine on lithic similarity and position in a sequence. Osberg (1980) regards the Waterville to be above the Vassalboro Formation, and to be of early Silurian age on the basis of three dendroid graptolite fossil localities. The Windham is thus assigned an Early Silurian age. The Windham may correlate with the Greenvale Cove Formation of Moench (1971) in the Rangeley area.

Vassalboro Formation

The Vassalboro Formation of the Portland-Gray is traceable into the type Vassalboro in the Augsuta-Waterville area. Osberg (1980) regards the Vassalboro Formation to be below the Waterville Formation. The age of the Vassalboro Formation is thus regarded to be Ordovician to Early Silurian. The Vassalboro probably correlates with the Quimby Formation of Moench (1971) of the Rangeley area.

Bucksport Formation

The Bucksport Formation is lithically similar to the Vassalboro Formation and also the the Berwick and Kittery Formations of southwestern Maine. Osberg and D. R. Wones (personal communications) have correlated the Bucksport with the Vassalboro despite the fact the two Formations are separated by the Norumbega Fault zone in the Bangor area. This would suggest a Late Ordovician to Early Silurian age for the Bucksport Formation. An alternative correlation is with the Merrimack Group in Southwestern Maine which, like the Bucksport, is also restricted to the southeast side of the Norumbega Fault Zone. If this correlation should be valid the Bucksport might be significantly older than Early Silurian (see discussion below relating to the age of the Merrimack group). A second alternative, not necessarily separate from the Merrimack correlation, is the possibility that the Bucksport may be a facies of the Cushing Formation. Notably, the Bucksport, particularly the thinbedded and calc-silicate-rich zones such as at Ocean Point, East Boothbay, is similar to the Sebascodegan Member of the Cushing. Both lie structurally, if not stratigraphically beneath pelitic and psammitic rocks of Cape Elizabeth type. This would render a correlation of Vassalboro with Bucksport (at least that of the Boothbay Harbor area) invalid.

Merrimack Group

The age of the Merrimack Group is very speculative. Billings (1956, p. 103-105) and other workers in New Hampshire have drawn attention to possible correlations of units of the Merrimack Group with the Silurian sequence (Vassalboro, Waterville and Mayflower Hill Formation) in central Maine. The writer originally correlated the Kittery, Eliot, and Berwick formations with the Mayflower Hill, Waterville, and Vassalboro Formations respectively, (Hussey, 1968, p. 299) the sequence described by Osberg (1968) in the Waterville-Augusta area. Subsequently, Osberg (1979, 1980) reversed the stratigraphic order of these three formations in Central Maine on the basis of new critical facing data at the Waterville/Mayflower Hill contact.

The key to the writer's original interpretation of a Silurian age for the Merrimack Group in southwestern Maine was the correlation, based on lithic similarity, of the Berwick Formation southeast of the Nonesuch River Fault with the Vassalboro Formation on the northwest side. Were it not for the presence of this inferred fault, there would be little basis for suggesting that the Vassalboro and Berwick Formations are different stratigraphic units. Such a correlation is strengthened by the fact that sequences in both areas are strikingly similar -- the Gonic/Gove is similar to parts of the Waterville/Windham, and the overlying pelite-bearing phase of the Berwick (NW of the Gove) is nearly identical to the Sangerville Formation which is conformably above the Waterville of the Central Maine Sequence. In this correlation, the Eliot and Kittery would be units below the Vassalboro of the Central Maine Sequence.

Workers in New Hampshire (Lyons et al., 1982; Bothner, et al., 1984; and Gaudette, et al., 1984) regard the Merrimack Group as Late Precambrian in age. Reasons for this age assignment are:

1) The Merrimack Group is intruded by the Exeter and Newburyport Plutons which give radiometric ages of 473 and 450 Ma respectively (Table I). They interpret these plutons to be post tectonic because they lack foliation and are unmetamorphosed.

2) The paragneiss of the Massabesic Gneiss Complex is dated at 646 Ma by Aleinikoff (1979) using U/Pb zircon methods. They interpret the zircons to be of volcanic origin thus giving the time of extrusion and deposition as Precambrian.

3) Inclusions of the Berwick formation are reported to be common in the orthogeneiss of the Complex which has yielded a zircon and Rb/Sr age of approximately 650 Ma (Besancon, 1977; Kelley, 1980).

Only the ages of the Newburyport and Exeter Plutons pose problems with a possible correlation of the Merrimack Group with the Central Maine sequence. The Massabesic does not, and the Newbury Volcanics may not. The writer correlates the Massabesic Gneiss with the Cushing and Cape Elizabeth Formations as previously noted, and xenoliths (or paleosomes in migmatite) noted within the Massabesic can all be accounted for as lithologies within the Cushing Formation. The Berwick Formation need not be involved. Furthermore, as discussed later under "structure", the Massabesic Anticlinorium does not exist. Instead, the writer interprets the Massabesic Gneiss to be part of a large-scale klippe similar to that described by Gates et al. (1984) and possibly emplaced by gravity gliding from source to the east. The unmetamorphosed Newbury volcanics close to regionally metamorphosed Merrimack Group rocks are fault bounded and may have been subjected to considerable strike-slip translation.

Smith and Barosh (1981) correlate the Berwick Formation with the Paxton and Oakdale Formations of Massachusetts, and Barosh and Pease (1981) suggest correlations, further, with the Southbridge and Hebron Formations of southern Massachusetts and Connecticut. These Berwick equivalents are regarded by them to be pre-Silurian in age from their inference that these formations have been subjected to intrusion, high grade metamorphism, and deformation of Taconic or older age. They regard the Eliot Formation as younger, affected only by low grade metamorphism and soft sediment deformation of Acadian age. These conclusions are not borne out by the writer's work in southwestern Maine and New Hampshire. Here the entire Merrimack Group forms a conformable sequence, and there is no evidence to indicate a difference in deformation, metamorphism and intrusive history between any units of the Merrimack Group.

A correlation of the Merrimack Group with the Silurian sequence of Central Maine cannot be ruled out. It must be kept as one of the working hypotheses. Another hypothesis is prompted by primary sedimentary structures in the Kittery Formation in the Kittery Ogunquit area. Small scale cross lamination consistently suggests a general east to west sedimentary transport direction after corrections are made for multiple deformation (Rickerich, 1983; Hussey et al., 1984). In contrast, regional facies relations strongly support a west to east sediment transport direction for the sedimentary sequence of central Maine. It is thus possible that the Merrimack Group and the central Maine sequence are two separate sedimentary packages with different source areas, having been juxtaposed by plate movements during closing of ocean Iapetus. These two packages may thus be of quite different age.

The writer agrees with Lyons et al. (1982) that "more field work is necessary to resolve the age of the Merrimack Group".

Gonic Formation

The Gonic Formation was included in the Shapleigh Group (Hussey, 1968) before complexities of regional correlation were known. Lithically it is quite similar to the Rindgemere in being pelitic, but is also similar to lenticular units of silvery muscovite-rich schist within Berwick-like lithologies, e.g. the Gove Member of the Berwick (Billings, 1956) in southeastern New Hampshire, and the Scotland Schist Member of the Hebron Formation in Connecticut (Barosh and Pease, 1981). I presently favor the interpretation that the Gonic is related to the Merrimack sequence. It should be noted that the Gove, to which it is similar, is part of that sequence mapped by Freedman (1950) as the Littleton Formation southwest of the Massabesic Gneiss (now no longer regarded as a valid correlation. If it were not for the Ordovician radiometric ages of the Newburyport and Exeter Plutons which intrude the Merrimack Group, a correlation of the Gonic and Windham/Waterville Formations would be attractive (Hussey, 1981), and the overlying pelite-bearing Berwick would easily correlate with the Sangerville. The age of the Gonic is designated ZD, Late Precambrian to Devonian until further work clarifies the relations of the Gonic to the stratigraphic sequence.

Shapleigh Group

Eusden (1984) correlates the Shapleigh Group with the northwestern Maine sequence, Rangeley through Carrabassett, thus assigning an Early Late Silurian to Early Devonian age to these rocks. Although the writer originally correlated the Group with Devonian metasediments of north central Maine (Hussey, 1968) he now considers the lower part of the sequence to be possibly of Silurian age. Table II is a summary of the writer's proposed correlation and a comparison with that suggested by Eusden (1984) and Eusden et al. (1984).

The writer separates the rusty schist exposed along the Spaulding Turnpike (stop 3 of Eusden et al., 1984) from the rusty schists of the Towow Formation and makes it a series of lenses at the top of the Lower Member of the Rindgemere. This is tentatively correlated with the Smalls Falls Formation of North-central Maine. The upper Rindgemere is equivalent to most of Eusden's (1984) Unit 4 and is correlated with the Carabassett Formation and Mount Blue Member of the Seboomook Formation. The Towow correlates with the Temple Stream Member of the Seboomook, and the unnamed unit above the Towow, part of Eusden's (1984) Unit 4, correlates with the Day Mountain Member of the Seboomook. The thin lenses of biotite and calc-silicate granulite mapped by Eusden (1984) may be Madrid equivalents, but it should be noted that they apparently occur within the non-rusty pelites above the rusty lenses, not at their contact.

In summary, the Lower Member of the Rindgemere is probably of Silurian age, and the Upper Rindgemere, Towow, and unnamed unit above the Towow are probably of Early Devonian age. However, I retain the Silurian-Devonian age designation for the entire Shapleigh Group on the chance that even the Lower Member of the Rindgemere might correlate with the Carrabassett Formation.

Table II. Correlations of the Shapleigh Group Formations with the North-Central Maine Sequence

	North-Central Maine	This Report	Corresponding Units of Eusden (1984) and Eusden et al. (1984), as interpreted by the author
DEVONIAN	SEBOOMOOK FORMATION		
	Day Mountain Member	Unnamed unit	Unit 4 (part)
	Temple Stream Member	TOWOW FORMATION	Unit 3 (part)
	Mt. Blue Member	RINDGEMERE FORMATION	Unit 4 (part)
	and		
	CARABASSETT FORMATION	Upper Member (thin lenses of biotite and calc-silicate granofels)	
SILURIAN	MADRID FORMATION		Unit 4A
	SMALLS FALLS FORMATION	Lower Member (rusty schist lenses)	Unit 3 (part)
	PERRY MOUNTAIN FORMATION	(upper part with coticule)	Unit 2
	SANGERVILLE FORMATION	(lower part with calc-silicate skarn lenses)	Unit 1

INTRUSIVE ROCKS

Introduction

Intrusive igneous rocks of the Portland and Bath 1x2° sheets range in age from Early Devonian to Cretaceous and constitute approximately 30% of the exposed crustal rocks. Included are basic and felsic calc-alkaline plutons alkaline and mafic plutons of the White Mountain Magma Series, and dike rocks (mostly mafic). The names of the different plutons are given in Plate 2, and reported radiometric ages are summarized in Table I. Estimated modes of many of the plutons are given in Appendix II.

Calc-alkaline Plutons

Calc-alkaline intrusive rocks originally assigned to the New Hampshire Plutonic Series constitute the most abundant and largest plutons in the map area. They range in size from lenses a few meters wide and a few tens of meters long to batholiths up to 90 km long (the Sebago Batholith, only partly exposed in the map area). Compositionally these plutons include gabbro, diorite, granodiorite, quartz diorite, and granite. Also included are the numerous pegmatite lenses and dikes that occur most abundantly in the terranes of sillimanite and sillimanite-K-spar grade regional metamorphism.

Basic to Intermediate Plutons

Exeter Pluton. The Exeter Pluton, referred to by most workers (Katz, 1917; Wandke, 1922); Novotny, 1969; Billings, 1956) as the Exeter Diorite, occupies an area 24 km long and 3 to 8 km wide in the towns of Exeter, Newmarket, Durham, Madbury, Dover, and Rollinsford, New Hampshire. Although dominantly of diorite composition, the Exeter pluton shows an irregular gradation from gabbro in the southwest to granite in the northeast (Gaudette, pers. comm.). The Pluton intrudes the Eliot and Kittery Formations, occupying the crest of the Exeter Anticline. Gravity studies by Bothner (1974) suggest an elongate body varying in thickness from 1 to 3 km. He postulates a syntectonic to post-tectonic emplacement during or slightly after the Acadian Orogeny; however Gaudette (1984) reports a Rb/Sr whole rock age of 473 Ma, indicating an Ordovician age of emplacement.

Saco Pluton. The Saco Pluton, originally named the Saco Diorite by Katz (1917), is an oval stock 5 km wide and 6 km long, slightly elongated in the direction of regional structural trends. It crops out in the towns of Saco and Buxton. It consists of medium dark gray to slightly greenish gray foliated and lineated metadiorite in which almost all primary silicate minerals are altered to secondary assemblages. Plagioclase, only occasionally fresh and of composition An_{35-47} (Hatheway, 1969) is extremely saussuritized. Hornblende and augite are almost entirely altered to fibrous amphibole. The contact zone with the surrounding country rock (Berwick, Vassalboro and Cape Elizabeth Formations) is extremely epidotized and lacking in relict diorite texture. Gaudette, et al. (1982) report a Rb/Sr whole rock age of 307 Ma (Mississippian which is close to the age reported by them for the Lyman Pluton just to the northwest. Hussey (1961) postulated a syntectonic emplacement and partial metamorphism during the Early Devonian Acadian Orogeny, but the 307 Ma age appears to be too young.

Quartz Diorite. Quartz diorite occurs as three lenticular plutons that crop out from Rochester, New Hampshire, for 13 km to the southwest. The three plutons measuring approximately 5 x 0.8 km, 6 x 2 km, and 10 x 3 km, intrude the Berwick and Gonic formations and Lower Member of the Rindgemere formation. The quartz diorite is weakly foliated medium dark gray, and fine-grained. the principal minerals present are plagioclase of intermediate composition, quartz, biotite, and hornblende. Spindle-shaped inclusions of country rock, generally well-digested, ranging from 1 to 20 cm in length and 0.5 to 4.5 cm in width, closely parallel the foliation (Stewart, 1961, p. 19).

Other Minor Plutons. Diorite forms a small lenticular pluton approximately 1.5 km long and 0.8 km wide in the town of North Berwick. This pluton is composed of medium-grained biotite-hornblende diorite that is very similar to the diorite of the Exeter Pluton. It crops out approximately 8 km northeast and on strike with the northern tip of the Exeter Pluton and may possibly be an extension of the pluton. This small pluton intrudes the Berwick Formation.

Acidic Plutons

Webhannet Pluton. The Webhannet Pluton, 27 km long and 3 to 8 km wide crops out from Wells south to Eliot, Maine. It is a late to post-tectonic pluton which intrudes the Kittery, Eliot, and Berwick Formations. It is elongate in a north-northeast direction, slightly oblique to the more northeasterly regional structural trend of that area. The Pluton consists of three phases which in the order of intrusion (oldest to youngest) are porphyritic granodiorite, gray biotite granite (originally referred to as quartz monzonite) and pink biotite-muscovite granite (Hussey, 1962).

The granodiorite occurs as isolated masses up to 5 km long within both the gray and pink granite phases. Age of the granodiorite relative to that of the other phases of the pluton is established by several stringers of gray granite cutting the granodiorite in the near-contact areas. The granodiorite is weakly foliated, medium gray, and fine to medium grained locally with phenocrysts of microcline up to 8 mm in diameter. These masses of granodiorite are either stoped blocks or roof pendants of the earliest intrusive pulse of the Webhannet Pluton.

Gray biotite granite forms the largest part of the Pluton. It is light medium gray, medium grained, generally equigranular, and very weakly foliated to massive. Varietal minerals include biotite, epidote, and magnetite.

Pink granite forms the northern end of the Pluton. It is light pinkish gray, evenly medium grained, and non foliated. Varietal minerals include biotite and minor muscovite. One observed contact between the pink and gray biotite granites demonstrates that these two varieties of granite were distinct intrusive pulses, but the relative age of the two is not clear. Both phases at this contact are closely intermingled suggesting the intrusion of one while the other was still plastic. The pink granite is assumed to be younger than the gray granite on the basis of its more silicaous composition and its total lack of foliation.

Gaudette et al. (1982) report a Rb/Sr whole rock isochron age of 391±42 Ma for the Webhannet Pluton. The large error they believe is due to the composite nature of the Pluton; this radiometric age determination is based on samples from all three phases of the Pluton. They also report U/Pb zircon age of 403±2 Ma determined from zircons from both the pink and gray granite phases.

Biddeford Pluton. The Biddeford Pluton occupies an area 15 x 10 km in the City of Biddeford, and Towns of Arundel and Kennebunkport. It crops out extensively along the coast between Cape Porpoise and Fortunes Rocks. The pluton is elongate in a southeast-northwest direction, intruding the Kittery, and Berwick formations in the area of a conspicuous major oroclinal flexure (see Plate 2). The Pluton is composed of evenly textured medium-grained light gray biotite granite. Foliation is virtually absent. Pegmatite is rare; one irregular stringer near Goose Rocks is reported to have yielded beryl and pink quartz.

Gaudette et al. (1982) report a Rb/Sr whole rock isochron age of 354±12 Ma for the Biddeford Pluton.

Lyman Pluton. The Lyman Pluton, 24 km long and 8 km wide, extends from Sanford northeast to the Saco River at Hollis. It is elongate parallel to regional structural trends and intrudes the Vassalboro Formation and the Lower Member of the Rindgemere Formation.

The southern half of the Pluton is composed of medium grained light gray to slightly pinkish gray non-foliated biotite granite with very minor muscovite. The northern half is fine-grained light gray weakly to moderately foliated biotite-muscovite granite. The nature of the boundary between the two lithic types, whether gradational boundary or intrusive contact is not known. Pegmatite lenses and stringers of common mineralogy (perthite, albite, quartz, muscovite, biotite, garnet, schorlite) are common throughout the northern half of the pluton and in the southern half are concentrated in near-contact zones.

Gaudette et al. (1982) reports a Rb/Sr whole rock isochron age of 322±12 Ma indicating a Mississippian age for emplacement of the Pluton.

The Lyman Pluton is probably a thin lenticular sheet dipping approximately 35° eastward. This inference is based on the observed dip of the contact exposed at the base of the Central Maine Power Company hydropower dam at Union Falls on the Saco River in Hollis, and also on the extensively developed late schistosity in the Vassalboro Formation. This schistosity which is parallel to the contact, is mapped up to 2 km on the east side of the Pluton but only a few tens of meters on the west side.

Sebago Batholith. Only the southern third of the Sebago Batholith is exposed in the Portland 1x2° map sheet. In general, the batholith is composed of light gray medium grained non to slightly foliated biotite-muscovite granite. The southwestern part of the Pluton in Maine is composed of fine-grained light to medium gray weakly foliated biotite granodiorite (Gilman, 1977), commonly intermixed with pegmatite and migmatized metapelite of the lower member of the Rindgemere. The two mica granite is younger than the granodiorite as determined from the presence of granite dikes in the granodiorite and granodiorite inclusions in the granite. Aleinikoff (1984) reports a zircon age of 325±3, or Mississipian, for the granitic main phase of the Sebago.

The Westbrook tongue of the Batholith is composed of medium gray granodiorite, light gray biotite granite, and pegmatites all intimately associated.

Unnamed Small Felsic Plutons. In the Kezar Falls-Newfield-Buxton area Gilman (1972, 1977) mapped several small plutons of two mica granite and granodiorite to quartz diorite. The granite is light gray fine grained nonfoliated Concord-type 2-mica granite. The granodiorite is characterized by uniform fine-grained texture and faint but pervasive foliation formed by parallelism of mica flakes. Biotite is the varietal mineral present.

Small lenticular plutons intrusive into the Vassalboro Formation ranging from 3 to 8 km in length and 0.5 to 1 km in width closely parallel the eastern and western contacts of the Westbrook tongue of the Sebago Batholith. These consist of fine grained light gray moderately foliated two-mica granite (Hussey, 1971a).

In the Bath-Brunswick area numerous elongate granitic plutons occur in the area of strong migmatization of the Cape Elizabeth Formation. These plutons are composed of fine to medium grained non-to rather strongly foliated light biotite-muscovite granite frequently with accessory garnet. Pegmatite stringers are common, frequently grading texturally into granite resulting n great heterogeneity of the texture of these plutons. Two small plutons near the north end of the Georgetown Island are composed of medium grained foliated medium-dark gray quartz diorite with biotite, hornblende, and relict augute.

Pegmatite. In areas of high metamorphic grade (sillimanite and sillimanite + K-feldspar) pegmatite lenses, stringers, and dikes are abundant both in the metasediments and metavolcanics and also in the felsic plutons of the New Hampshire Plutonic Series. Pegmatites are particularly concentrated in the Topsham-Brunswick-Freeport-Cumberland area, the Georgetown and Phippsburg to Bath area, and the Sanford-Kezar Falls area. Mineralogically, pegmatites in these area consist of a common mineral assemblage of quartz, perthitic microcline, albite (only rarely in the form of strongly twinned cleavelandite), biotite, muscovite, and garnet. Black tourmaline (schorlite) in well-developed trigonal prisms is common but not obiquitous. Less common is beryl in well developed hexagonal prisms, chrysoberyl and secondary uranium minerals. The more exotic minerals of pegmatites such as spodumene, triphyllite, red, blue and green tourmaline, pink quartz, purple apatite, among others, are not reported or are exceedingly rare. Lepidolite, etched topaz crystals, herderite, and morganite were recovered from a pocket in the Fisher Quarry in Topsham (Palache, 1934) but are not known from other localities in the discussion area. Pegmatites from within the outcrop belt of the Cape Elizabeth Formation have pink potash feldspars and show evidence of aluminum assimilation from the country rock; fibrolitic sillimanite is locally very common. These pegmatites also carry very sparing amounts of dumortierite, chalcopyrite, bornite, and secondary copper minerals.

Concordant pegmatite lenses and stringers are commonly foliated and folded indicating a syntectonic origin. Discordant pegmatites with even parallel matched walls, and frequently with tourmaline prisms developed perpendicular to the walls, are generally non-foliate and coarser grained than the concordant ones. Brookins and Hussey (1978) report a Rb/Sr age for foliated and nonfoliated pegmatites in the Falmouth-Cumberland, Maine area of 385 to 375 Ma.

Miscellaneous Premetamorphic Intrusive Rocks

Lincoln Sill. The Lincoln Sill, named by Trefethen (1937) for Lincoln County, is a discontinuous series of syntectonic premetamorphic lenses of mafic syenite of general shonkinite affinity (Pankiwskyj, 1978). These lenses extend from Boothbay Harbor north-northeastward 80 km to the area of Liberty, Maine. Within the Bath 1x2^{o} sheet, the sill is represented by a single lens varying from 75 to 200 m in thickness centered around the Boothbay Harbor area. Here it lies concordantly within the Bucksport, but close to the contact with the Cape Elizabeth Formation. After intrusion it was folded along with the metasedimentary sequence around the Boothbay Antiform, intruded by pegmatites, and metamorphosed.

The Lincoln Sill exhibits two textural and mineralogical phases. In the wider parts of the Sill, central portions retain original igneous texture and primary mineralogy. In such areas it is a dark brownish gray strikingly porphyritic mafic syenite consisting of purplish gray zoned phenocrysts of alkali feldspar in a medium grained groundmass of alkali feldspar, hornblende, augite, biotite, and rarely orthopyroxene. Phenocrysts are euhedrally zoned with composition ranging from $Or_{55}Ab_{45}$ to $Or_{85}Ab_{15}$ (Elders, 1969, p. 272), and are frequently greater than 4 cm long. The marginal portions of bulges of the sill and the entire mass of the sill where it is thin have been metamorphosed to a dark gray biotite-hornblende schist with conspicuous purplish gray to milky white feldspar megacrysts (relict phenocrysts) which retain some of the original euhedral compositional zoning.

Edgecomb Gneiss. An orthogneiss 100-200 m wide intruded concordantly along the Cape Elizabeth-Bucksport contact was mapped by Hatheway (1969) in the Wiscasset 15' quadrangle. The writer (Hussey, work in progress) has mapped this gneiss 4.2 km southward into the present map area within the Bucksport Formation, but close to the Cape Elizabeth-Bucksport contact just east of the Sheepscot River. This orthogneiss is a medium gray quartz-plagioclase-biotite-hornblende gneiss with conspicuous feldspar augen up to 1 cm. This unit was referred to by Hatheway as the Edgecomb Gneiss.

White Mountain Magma Series

Post-orogenic stocks and ring complexes of Late Permian or Early Triassic to Cretaceous age occur in a northwest-trending belt extending from York on the south through Brownfield on the north and thence into New Hampshire (Hussey, 1962; Gilman, 1977; 1972). These plutons are formed from two distinct petrographic rock suites: 1) alkaline syenite, quartz syenite, and granite; and 2) basic plutons with intermediate to acidic differentiates. The alkalic plutons range in age from Late Permian to Cretaceous in age, while the basic complexes are of Cretaceous age only.

Alkalic Plutons

Agamenticus Complex. The Agamenticus Complex is a roughly circular complex approximately 10 km in diameter composed of four plutonic phases (Hussey, 1962). Age relations between the three older phases are not well understood. The presumed oldest phase is medium grained brown to olive-green syenite composed of microperthite, riebeckite, arfvedsonite, hastingsite, aegirine-augite, aegirine, and enigmatite. Quartz is present in amounts less than 2%. This phase forms an irregular oval 3 x 7 km within the complex but close to the northeastern margin. The presumed next younger phase is alkaline quartz syenite that forms an irregular ring intrusive cutting through the northeastern part of the syenite but surrounding it and the biotite granite phase in the other parts of the complex. It is similar in mineralogy to the syenite except for a greater amount of quartz (10-15%). Along the southeastern and southern parts of its outcrop belt, this phase consists of blocks of variably textured syenite cut by stringers of alkaline granite. Distinction between blocks and stringers becomes more diffuse to the north suggesting that the alkaline quartz syenite may be the result of marginal contamination of alkaline granite by stopped blocks of alkaline syenite. Alkaline granite forms two bodies within the complex. The larger is a partial ring structure 3 km wide and 15 km long on the north and west sides of the Complex. The smaller one occupies a half-oval area 2 x 3 km in dimension on the southeast side of the Complex near York Beach. The larger body is presumed to be younger than the alkaline syenite, but the smaller one may be older phase based on the apparent cutting of it by the alkaline quartz syenite as suggested by the map pattern. The larger alkaline granite mass is medium grained and light gray in color, whereas the smaller body is fine-grained and buff to slightly salmon-colored. Both bodies have the same assemblage of Na-rich pyroxenes and amphiboles as the syenite. The youngest phase of the Complex is a fine to medium grained light pink porphyritic biotite-hornblende granite closely resembling the Conway-type granite bodies of New Hampshire.

Foland and Faul (1977) report a K/Ar age of 228 $\pm$ 5 Ma (Late Permian to Early Triassic) for biotite from the alkaline granite. This is in agreement with a Rb/Sr whole rock isochron age reported by Hoefs (1967).

All phases of the Agamenticus complex are cut by Late Triassic to Cretaceous dikes described below. The alkaline granite cuts the gray biotite granite of the Webhannet Pluton.

Abbott Mountain Stock. The Abbot Mountain Stock (Gilman, 1972) is an oval pluton occupying an area 2 x 3 km just east of the village of North Shapleigh. It is composed of coarse-grained brownish gray alkaline syenite consisting of more than 90% subhedral to anhedral microperthite (occasionally microantiperthite) and approximately equal amounts of aegirine-augite and fayalite (Gilman, 1972). According to Gilman a marginal phase transitional to the main part of the syenite contains a small percentage of quartz. Foland and Faul (1977) report a K/Ar age of 221 $\pm$ 8 Ma which is very close to that of the Agamenticus Complex, the syenite of which is very similar in appearance to the Abbott Mountain syenite. Christopher (1969) reports a fission track age of 119 Ma.

Pickett Mountain Stock. The Pickett Mountain Stock was mapped and named by Gilman (1972). It is a 3 x 4 km oval pluton exposed on Pickett Mountain just south of Newfield Village. It is intrusive into the Devonian age granodiorite pluton of the Newfield area. It is composed of homogeneous gray-brown medium-grained equigranular to subporphyritic biotite-hornblende granite. No radiometric dates are reported for this pluton.

Symmes Pond Stock. The Symmes Pond Stock, mapped and named by Gilman (1972) is a 1 x 1 km pluton of alkaline syenite identical to the main phase of the Abbott Mountain Stock. It intrudes the same granodiorite as the Pickett Mountain Stock and lies approximately 0.12 km northwest of that pluton. No radiometric dates are available for this pluton.

Randall Mountain Stock. The Randall Mountain Stock is a 1 x 3 km pluton exposed on Randall Mountain 2.5 km southwest of the village of East Parsonsfield. According to Gilman (1972) this pluton consists of variably textured gray-brown syenite, and gray fragmental trachyte porphyry. The syenite varies in texture from fine-grained equigranular to medium grained porphyritic. Gilman reports minor amounts of nepheline and sodalite. Fragmental trachyte porphyry occurs as dikes cutting the syenite, and also as inclusions. Gilman regards the trachyte to be in part of volcanic origin. The Randall Mountain Stock intrudes migmatized metapelitic and calc-silicate gneisses of the Lower Member of the Rindgemere Formation. No radiometric dates are available for the pluton.

Burnt Meadow Complex. Alkaline syenite, quartz syenite, and fragmental to nonfragmental trachyte, quartz trachyte, and andesite have been described by Gilman (1977) from Burnt Meadow Mountain in Brownfield. The complex is 7 km long and 3 km wide.

Alkaline syenite, which comprises approximately a quarter of the complex, is brownish gray, medium to coarse grained and occasionally porphyritic. Microperthite constitues 95% of the rock, and unspecified máfic minerals, the remaining 5%. Quartz syenite, comprising approximately half the complex, is fine-grained, porphyritic (the phenocrysts up to 15 mm long), and tan to pinkish in color. Average mineral proportions given by Gilman are 70% orthoclase, 20% plagioclase, 5% quartz, and 5% unspecified accessories and varietal minerals. Gilman regards the syenite to be older than the quartz syenite.

The aphanitic rocks include medium-gray non fragmental trachyte and andesite porphyry, and fragmental gray porphyries. The fragmental rocks also include basalt, schist, and granite fragments, but virtually no syenite or quartz syenite which leads Gilman to suggest that the fragmental rocks predate emplacement of the plutonic phases. He suggests that the fragmental rocks are large blocks of surface volcanics that have been preserved from erosion by engulfment in the plutonic phases of the Complex.

Foland and Faul (1977) report a K/Ar age of 108 $\pm$ 2 Ma for the syenite of the Complex thus making the Burnt Meadow Complex the youngest pluton of the White Mountain Plutonic Series in southwestern Maine.

Boston Hills Stock. Gilman (1977) maps a small 1 km diameter stock of medium grained brownish syenite underlying the Boston Hills 3 km southwest of the village of Denmark. No radiometric age is availble for this pluton. It intrudes granodiroite of the southern part of the Sebago Batholith.

Whales Back Pluton. Whales Back Ridge which straddles the Maine-New Hampshire border 7 km west of Burnt Meadow Mountain is underlain by pink to gray medium to coarse grained biotite granite (Gilman, 1977). Wilson (1969) maps the continuation of this granite in the Ossipee Lake 15' quadrangle to the west and correlates it with Conway-type granite of the White Mountain Magma Series. Foland and Faul (1977) give a K/Ar age of 184 ± 4 Ma for this pluton.

Basic Plutons and Related Breccias

Basic plutons, all of presumed Cretaceous age, of the Portland 1x2° map sheet include the Cape Neddick Complex, Tatnic Complex, Alfred Complex, Lebanon Stock, and Acton Stock. Two small explosion breccias in the Rye Formation on Gerrish Island, Kittery, are correlated with this basic intrusive activity.

Cape Neddick Complex. The Cape Neddick Complex is a small (0.5 x 1 km) composite basic pluton exposed on Cape Neddick Peninsula in York Beach (Hussey, 1962). The Complex consists of two intrusive units. The older one, injected as a funnel intrusion, consists of gabbro grading inward into anorthositic gabbro. Mineralogy of the gabbro and anorthositic gabbro is augite, hornblende, biotite, serpentine after olivine, magnetite, and complexly composition-zoned labradorite (occasionally with cores as calcic as bytownite). The ratio of dark minerals to labradorite is approximately 50/50 for the gabbro and 20/80 for the anorthositic gabbro. Both gabbro and anorthositic gabbro show well developed layering of a variety of types (see Hussey, 1962). The younger intrusive unit is injected as a central funnel intrusion and two partial cone sheets within the older anorthositic gabbro. The cone sheets and marginal parts of the funnel consist of dark gray poikilophytic cortlandtitic gabbro. The cortlandtitic gabbro of the marginal parts of the central funnel grades inward into medium dark gray gabbro. Mineralogically the cortlandtitic gabbro consists of hornblende (which forms conspicuous poikilocrysts up to 3 cm in diameter), augite, fresh olivine, biotite, labradorite (with cores of bytownite), magnetite, and hypersthene. The marginal cortlandtitic gabbro has a plagioclase/dark mineral ratio of about 20/80, whereas the central portion has a ratio of approximately 50/50.

The complex intrudes the Kittery Formation and a small body of explosion breccia which the writer correlates with the breccia bodies on Gerrish Island, Kittery. The explosion breccia consists of fragments up to 5 cm in diameter of both the Kittery Formation and light and dark-colored aphanitic volcanic or shallow hypabyssal rocks.

Foland and Faul (1977) report a K/Ar age of 116 ± 2 Ma for the gabbro of the outer funnel intrusion.

Tatnic Complex. The Tatnic Complex is a 3 x 5 km composite pluton underlying the Tatnic Hills in North Berwick and South Berwick. It intrudes the Kittery Formation and the granodiorite and gray granite phases of the Webhannet Pluton. The Complex consists of two phases, an older fine-grained noritic gabbro with strongly developed igneous lamination grading inward and upward into coarse-grained anorthositic gabbro; and a younger olivine gabbro that in places grades inward and upward into quartz diorite, but in places is intruded by the quartz diorite (probably due to the subsidence of portions of the magma chamber floor after consolidation of the olivine gabbro but before consolidation of the quartz diorite). Cobble and pebble-size inclusions are abundant in the quartz diorite. Larger inclusions within the younger phase, some up to 100 m across, include 1) blocks of varying size of dark porphyritic basalt representing cognate inclusions of marginal chill phases of noritic gabbro and olivine gabbro; 2) large blocks of volcanic breccia; and 3) blocks of hornfelsic Kittery Formation. On Browns Hill in the southwestern edge of the Complex, one large block consists of volcanic breccia resting on Kittery lithology. Fragments in the breccia are light and dark colored aphanites, dark basalt porphyry, quartzites of the Kittery Formation, anorthositic gabbro and noritic gabbro. The latter two lithologies indicate that the breccia formed after consolidation of the older noritic gabbro-anorthositic gabbro phase. The light and dark colored aphanites are interpreted to be surface volcanics related to the compositionally stratified olivine gabbro-quartz diorite subjacent magma chamber.

Foland and Faul (1977) report a K/Ar age of 122 $\pm$ 2 Ma for biotite from the Tatnic Complex.

Alfred Complex. The Alfred Complex, underlying an approximately 15 km^2 hilly area just west of the village of Alfred, consists of three phases, noritic gabbro (oldest), monzodiorite, and porphyritic granodiorite (youngest), intruded into metapelites and calc-silicate rocks of the Lower Member of the Rindgemere Formation. The noritic gabbro, forming a funnel intrusion, is fine to medium grained, dark brownish gray, and has a well developed igneous lamination dipping toward the center of the funnel. This lamination is best developed in the central two thirds of the pluton and is essentially absent in the marginal parts. The mineralogy of the noritic gabbro is labradorite, hypersthene, augite, brown hornblende, brown and green biotite, magnetite, apatite, and up to 2% quartz. Two thin (less than 10 m) layers of anorthosite are present close to the center of the pluton. They are conformable with the igneous lamination of the noritic gabbro.

Monzodiorite is medium light gray in color, medium-grained, and choked with inclusions of well digested country rock 3 to 10 cm in diameter. It closely resembles the quartz diorite of the Tatnic Complex. Mineralogy of the monzodiorite is andesine, green hornblende, green biotite, magnetite and sparing amounts of augite and hypersthene, usually as residual cores in hornblende. The monzodiorite forms a 500 m wide ring dike that cuts out the southwestern third of the noritic gabbro.

Porphyritic granodiorite is light buff gray, fine to medium grained, seriate porphyritic, and composed of andesine rimmed by orthoclase, quartz, green biotite and occasionally green hornblende. It forms a 1.5 x 2 km central stock completely ringed by the monzodiorite.

Foland and Faul (1977) report a K/Ar age of 120 $\pm$ 2 Ma for the gabbro phase of the Alfred Complex.

Lebanon Pluton. The Lebanon pluton is a 2 km diameter stock of diorite/gabbro that crops out in the town of Lebanon 6 km southwest of Sanford (Hussey, 1962). It consists of dark gray andesine/labradorite, augite, hornblende, biotite, and magnetite. Layering and igneous lamination are absent. Foland and Faul (1977) give a K/Ar age of 125 $\pm$ 3 Ma for the Lebanon Pluton.

Acton Stock. The Acton stock (Gilman, 1972), a 1 km diameter pluton located 2 km south of the village of Acton, consists of medium-grained greenish gray quartz diorite and dark gray andesite breccias with fragments of schist and aphanitic rocks that may be of volcanic origin (Gilman, 1972). The Acton stock is intrusive into the Upper and Lower Members of the Rindgemere Formation.

Explosion Breccias on Gerrish Island. The writer (Hussey, 1962) described two explosion breccias on the eastern shore of Gerrish Island, Kittery. The southern of the two is the larger, and consists of closely packed angular fragments ranging from 1 cm to 1 m in diameter. Fragments are primarily of local lithologies of the Rye Formation including migmatized blastomylonite, calc-silicate, and amphibolite, plus an earlier set of diabase dikes. Also included are small blocks of light gray felsite possibly representing surface felsic volcanics, and/or intrusive dikes which intrude the Rye Formation nearby. The breccia is cut by a second set of diabase dikes including a major one 30 m wide and trending northwest. The breccia is isolated from non-brecciated Rye Formation by an irregular 1/4 to 3 m wide light buff felsite porphyry dike. This felsite dike is cut by the younger set of diabase dikes.

The northerly and smaller of the breccia bodies is poorly exposed along the eastern shore 3/4 km north of the above described body. It consists of 10 cm to 5 m blocks of the local Rye lithologies and one distinctive block, 5 m long, of thin to medium bedded Kittery Formation.

These breccias are correlated with the breccia at the margin of the Cape Neddick pluton and are probably of Cretaceous age.

Basic and Felsic Dikes

Dikes of the Portland and Bath 1x2° sheets have been studied by Lord (1899), Keeley (1914, 1924), Kemp (1890), Powers (1915), Haff (1939, 1941, 1943), Ogilvie (1907), McHone (1982), Swanson (1982), Hussey (1962), and Hussey, et al. (1984).

Basic dikes, and less commonly, felsic dikes form a dike swarm in a 15 km wide NNE-trending belt extending along the shoreline from Kittery to the vicinity of Fortunes Rocks between Biddeford Pool and Kennebunkport. Northeast of this the swarm either dies out or trends out to sea. In this belt, basic dikes occasionally constitute as much as 35% of the rocks exposed such as in parts of the Kittery area, and frequently 15-20%. Outside of this coastal belt basic dikes are wide spread but much less common.

The dikes are composed mostly of basalt or diabase (both equigranular and porphyritic) with less common camptonite, monchiquite, and felsite. They are non metamorphosed but frequently show a wide variety of deuteric alteration effects. It is not uncommon to observe in adjacent dikes that plagioclase phenocrysts are completely saussuritized and dark minerals such as augite, and especially olivine are unaltered, whereas in another the reverse is true, while in still others dark and light mineral phenocrysts are either both fresh or both altered. Many dikes are multiple with two or more parallel dike members, both intrasectate and extrasectate. Occasionally a basalt or diabase dike is centrally intruded by a felsite dike but the relationship is not that of a composite dike because the felsite is chilled against the basaltic. A few trachyte dikes in the York Beach-Ogunquit area generally showing strong flow banding and blue-colored chill margins are of alkalic affinity (aegirine and riebeckite-bearing) and are probably apophyses from the Agamenticus Complex. These alkalic trachyte dikes are the oldest dikes of the area; they cut no dikes, basic or felsic, but are cut by them.

Inclusions of a variety of rock types are common in diabase and camptonite dikes. Among the rock types represented are local country rock, alkaline granite, alkaline syenite, granite of unknown chemical affinity, gabbro, ultrabasic rocks, and high-grade graphitic and garnetiferous quartzo-feldspathic gneiss possibly related to the Rye Formation or unexposed basement terrane.

Cross-cutting relations among dikes in dike swarms indicate up to 5 episodes of local dike injection. There seems to be no correlation between composition and order of intrusion. Dikes in the Kittery Formation in the coastal swarm belt have been injected largely parallel to steeply dipping bedding and trend generally N 50-60° E. In the Rye and Kittery Formations on Gerrish Island, the dikes trend generally N 25 E and cause, by their cumulative dilation effect, a noticeable change in the regional strike of minor map units and the Rye-Kittery contact, as compared to local strikes at individual exposures. Although radiometric data are lacking for these dikes, Swanson (1982) suggests an Early Triassic to Early Jurassic age for intrusion of the N 50-60° E swarm and Late Jurassic to Early Cretaceous age for intrusion of the N 25 E trending swarm (Gerrish Island Swarm).

STRUCTURE

Folding

Introduction

The Shapleigh, Casco Bay, and Merrimack Groups, the Central Maine Sequence, and the Bucksport have each been affected by two major fold deformations, the earliest being recumbent and the later being upright to slightly overturned. In addition they have been affected by several minor events including the development of slip cleavage, crenulations, and kink bands. The deformational history of the Benner Hill Sequence is not clearly known but is probably equally as complex.

The macroscopic fold system that controls the major map pattern of each sequence is the second major deformation of each (F_2 as described below) involving upright to slightly overturned folds, with north to northeast-trending fold axes, gentle to moderate angles of plunge, and frequent reversals of plunge direction. The designations F_1, F_2, etc. apply to sequences of folds for each major stratigraphic sequence, and no correlation or synchroneity of development is implied between sequences -- i.e., F_1 of the Casco Bay Group was not necessarily developed at the same time as F_1 of the Merrimack Group, or the Shapleigh Group, etc. The time of deformation will be discussed in a later section of this report.

Casco Bay Group Deformation

The deformational history of the Casco Bay Group is best understood from shoreline exposures in the Small Point area of Phippsburg and the Cape Elizabeth area.

In the Small Point area F_1 structures are mesoscopic to macroscopic scale recumbent isoclines of unknown facing direction. These may be related to major recumbent folds of scale comparable to those postulated by Osberg (1980) for the Silurian sequence of central Maine, but definitive evidence for such large scale structures is virtually lacking in the rocks of the Casco Bay Group. S_1 structures include and axial plane schistosity in the pelitic beds and a closely spaced fracture cleavage in the more quartzose beds. Locally (only observed at Bald Head on Small Point) S_1 fracture cleavage has been recumbently and very tightly folded. Because of very limited and local development, these folds are not designated as F_2. F_2 structures include small-scale mesoscopic upright to slightly overturned asymmetric open folds of bedding, muscovitic S_1 schistosity, and axial surfaces of folds of the S_1 fracture cleavage noted above. Locally biotite has been partially recrystallized to form an S_2 schistosity axial planar to F_2. These F_2 structures are congruent with macroscopic folds defined by the map pattern of minor lithic units in the Small Point area.

In the Harpswell and Scarboro-Portland areas to the west, major folds defined by the map pattern (Hussey, 1971a, 1971b) correlate with F_2 thus indicating that this deformational event was a major one of regional extent. In these areas, F_2 structures are much tighter than in the Small Point area, making very difficult the distinction between F_1 and F_2 fold hinges, particularly as biotite and muscovite both are recrystallized here parallel to the F_2 axial planes. In the Orrs Island and Portland-Scarboro areas subsequent folding events were of minor nature: F_3 and F_4 are minor crenulations of earlier lineations and schistosity and F_5 are steeply dipping kink bands with quite consistent left-lateral kinking sense. Kink bands are best developed in the Cape Elizabeth and Macworth Formations, and are frequent enough locally to divert formational contacts by as much as 20° from the locally measured strike of bedding.

Within the Cape Elizabeth Formation at Two Lights State Park (Hussey, 1982) and the Ram Island Farm area (Hussey, 1978) recumbent eastward-facing F_1 parasitic folds with a west over east asymmetry sense, indicate that the Formation exposed there is on the upper, upright, limb of an east-facing recumbent anticline. F_2 folds (in the Small Point chronology) are very gentle and open with gentle plunges. Similar geometry but with reversed asymmetry affects the Cape Elizabeth-Cushing contact exposed at Chimney Rock approximately 1 km south of Portland Headlight. Here the Cushing Formation is structurally on top of the Cape Elizabeth Formation, but graded beds near the contact indicate that the sequence is upside down. F_2 parasitic folds here are moderately open, plunge gently southwest, and clearly deform the inverted limb of a recumbent fold.

Osberg (1974) referred to the outcrop belt of the Casco Bay Group between Wiscasset and Orrington as the Liberty-Orrington Anticline (also the Orrington-Liberty Anticlinorium). This was based on the axial position of the Casco Bay Group of Cambro-Ordovician age between the Vassalboro Formation of Siluro-Ordovician age on the west and the Bucksport (correlated as the age equivalent of the Vassalboro) on the east. This positioning of older rocks between younger does not appear to be simply fold controlled. The macroscopic F_2 map pattern for the Casco Bay Group as a whole in the Scarboro-Portland-Bath area defines crudely an F_2 synclinorium, not an anticlinorium. To accommodate this pattern with younger rocks flanking this synclinorial belt, it is necessary to invoke large scale low angle premetamorphic faulting in which rocks of the Casco Bay Group have been emplaced as a large thrust or gravity glide sheet. The writer suggests that the Casco Bay Group is a synclinorially-folded klippe resting upon the Vassalboro-Bucksport sequence and furthermore that the root zone for the klippe may lie in the Rockland-Camden area east of the Bucksport outcrop belt. This klippe may be an extension of the zone of thrust stacking described by Osberg and Guidotti (1974) for the Camden-Rockland area.

Merrimack Group Deformation

Three principal fold sets deform the Merrimack Group. These are best seen along the Marginal Way, a public shoreline foothpath in Ogunquit (Hussey et al., 1984), and along the shoreline between Perkins Cove in Ogunquit and Bald Head Cliff in York. The earliest folds, F_1, are south-facing mesoscopic recumbent isoclines probably parasitic to much larger scale recumbent folds. They are best exposed along the Marginal Way. F_2 folds are upright open to slightly overturned tight folds with plunges up to, but generally less than 30°. Reversals of plunge and directions of overturning are common. These folds, where tight, have a well-developed axial-plane cleavage, S_2, with prominant bedding transposition in hinge areas. F_3 folds are relatively open, overturned, generally dextral fold sets with well-developed strain-slip cleavage, S_3, and prominent bedding transposition in hinges. F_3 locally refolds F_2 hinges. Two unfolded .3-.5 m thick metafelsite dikes with a penetrative S_3 fabric, to be seen along the Marginal Way, indicate minor syntectonic igneous activity associated with F_3 development.

Macroscopic hinges of F_1 structures have not as yet been mapped. Macroscopic F_2 folds, which control the distribution of the Kittery and Eliot Formations are the Great Bay Synform and the Exeter Antiform (largely occupied by the Exeter Pluton). In the Eliot area, the Great Bay Synform bifurcates northward forming the South Berwick and Eliot Synforms and an intervening antiform. A synform west of the Exeter Antiform inferred by Lyons, et al. (1982) is not indicated or suggested by present mapping; neither the Eliot nor the Kittery Formations are repeated west of the outcrop belt of the Berwick in the Raymond-Epping, New Hampshire, area. Correspondingly, there is no evidence that the Massabesic Gneiss occupies the core of an anticlinorium as suggested by Lyons, et al. (1982).

In the Biddeford-Kennebunk-Kennebunkport-Biddeford Pool area, the structural trends of the Merrimack Groups have been deflected through an angle of nearly 150° in a structure referred to here as the Kennebunk flexure. This structure appears to post-date F_2 structures because the orientation of axes and axial planes of F_2 parasitic folds appear to be similarly deflected; they are not congruent to it. The Kennebunk flexure predates the post-tectonic Mississippian-age Biddeford Pluton.

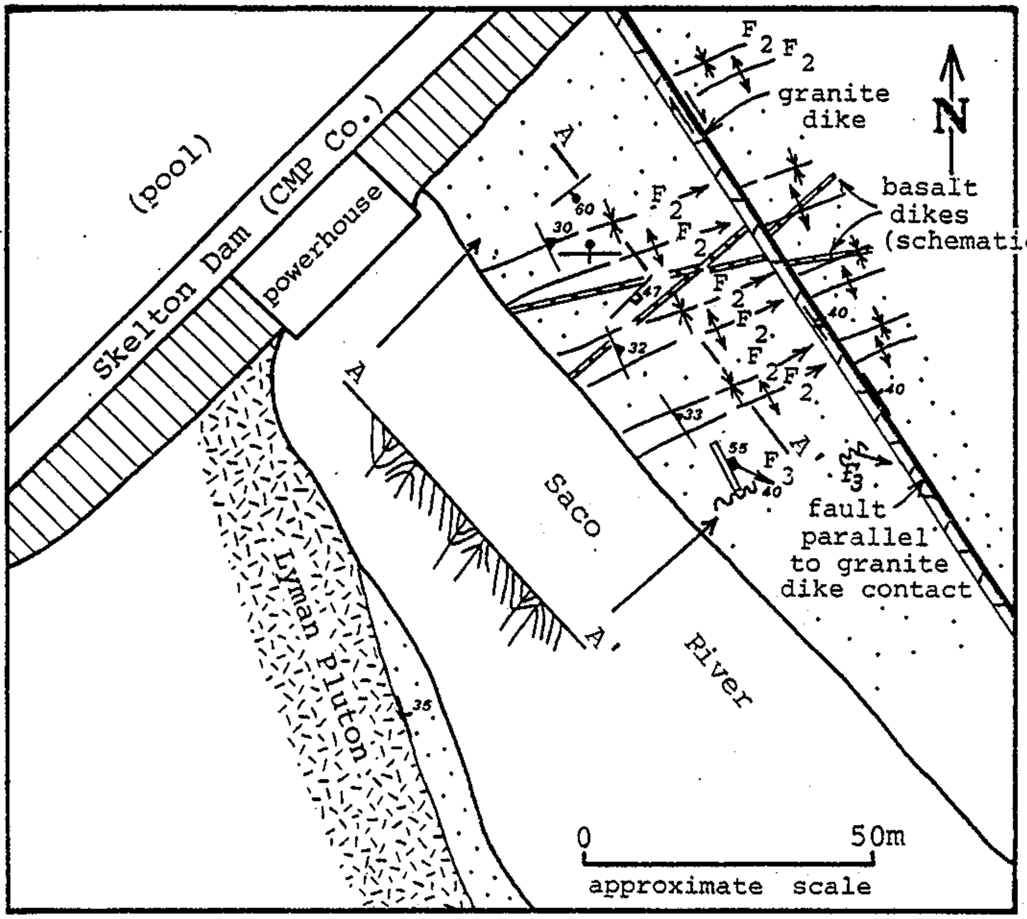
Deformation of the Central Maine Sequence

The earliest folds (F_1) of the Central Maine Sequence are large-scale recumbent east-facing isoclines involving the Vassalboro, Waterville, Sangerville, Perry Mountain, Smalls Falls, and Madrid Formations. Existence of these folds is indicated by the presence of occasional downward-facing mesoscopic-scale F_2 folds mapped by Osberg (1968, 1980) in the Waterville area. Hinges of recumbent folds have not been observed. These folds have been refolded by large-scale upright to slightly overturned tight to isoclinal F_2 folds that in general control the map pattern. Axial traces of F_2 folds trend northeast, and axes plunge up to 40° both to the northeast and southwest. Macroscopic F_2 folds that affect the Windham and Vassalboro Formations are shown on Plate II. Mesoscopic F_2 folds are well exposed in the map area in outcrops at the base of the dam at Union Falls on the Saco River at Buxton, and in a large rock quarry 2 km west of Gorham. At the former locality (Figure 3) F_2 folds are upright, steeply overturned to the southeast, and have axial traces trending approximately N 30 E. Axes plunge moderately to the northeast. F_2 folds here are refolded by small-scale F_3 folds that have axial planes overturned to the west dipping roughly parallel to the contact of the Lyman Pluton with the Vassalboro Formation. An S_3 schistosity parallel to the axial planes of these folds has nearly obliterated earlier cleavages, and is developed in an aureole extending approximately 1.5 km to the southeast of the pluton. F_3 folds are clearly related to the emplacement of the Lyman Pluton. At the Gorham rock quarry F_2 folds are upright, upward facing, northeast-plunging isoclines. They have not been refolded.

Roadcuts in migmatized Vassalboro Formation along I-95 and I-295 in Falmouth show occasional east-verging folds that deform both bedding, gneissic foliation and semiconcordant foliated syntectonically emplaced pegmatite lenses. These are cut by discordant evenly textured, non-foliated pegmatite dikes. Both sets of dikes yield essentially similar Rb/Sr whole rock ages of 375-385 my (Brookins and Hussey, 1978).

Shapleigh Group Deformation

The outcrop pattern of the Upper Member of the Rindgemere Formation, the Towow Formation, and the unnamed unit above the Towow is determined by what was originally referred to as the Lebanon Syncline (Hussey, 1962). Recognition that this structure is dominated by east-facing overturned beds and relatively few upright west-facing beds led Eusden (1984) to reinterpret this as a downward-facing antiform. The Lebanon Antiform is thus a macroscopic easterly-overturned doubly-plunging F_2 structure that refolds the inverted limb of a regionally more extensive west-facing F_1 recumbent anticline. According to Eusden, et al. (1984) the hinge of this fold lies in



Strike and dip of upright bedding

Strike of vertical bedding (tops in direction of ball)

Strike and dip of schistosity (S_3)

Strike and dip of granite foliation

Strike and dip of axial planes, and plunge of axes of F_3 folds

Contact showing dip where known

Strike-slip fault showing dip

Vassalboro Formation

Two-mica granite

Figure 3. Geological sketch map of the ledges exposed at the foot of the Skelton hydroelectric dam, Saco River, Buxton.

the Blue Job Mountain area approximately 11.5 km WNW of Rochester, New Hampshire, and trends NE into Maine near Milton, New Hampshire. Recumbent mesoscopic F_1 parasitic folds are exposed in a few outcrops, particularly of the marble and calc-silicate horizon within the Lower Member of the Rindgemere (Gilman, 1977). Where the Lower Rindgemere is strongly migmatized, there is little or no consistency in strike or fold trends. However, Gilman (1977) outlines two major structures, the Pequaket Synform and the Hiram Antiform in the Kezar Falls 15' quadrangle based on broad statistical trends of dip of foliation and schistosity. These broad structures probably relate to migmatization and pluton emplacement.

Much of the outcrop belt of the Lower Member of the Rindgemere Formation in the Kezar Falls and Newfield 15' quadrangles is characterized by northwest trending outcrop belts of calc-silicate and rusty schist, and strikes of bedding and foliation; west of Center Lebanon in the Berwick 15' quadrangle the contact between the Upper and Lower Members is deflected into an open northwest fold. These northwest structures are tentatively interpreted to be deflections of F_2 structures due to the emplacement of the Sebago Pluton and not to a separate northeast-southwest directed orogenic impulse.

In the Berwick quadrangle, rocks of the Shapleigh Group, including the Gonic Formation, are cut by a strong crenulation and slip cleavage representing the latest structural feature of these rocks.

Faults

Major faults in the map area are shown in Plate 2. Types of faults that have affected the rocks of this area include folded thrust faults, post metamorphic but preplutonic strike slip faults, and post-metamorphic and post-plutonic gravity faults.

Folded, Premetamorphic Faults

Two inferred folded thrust or gravity glide faults separate major sequences in the study area:

1) between the Casco Bay Group (upper plate) and the Vassalboro, Bucksport, and Berwick Formations (lower plate);

2) between the Central Maine Sequence (upper plate) and the Shapleigh Group (lower plate).

The contact between the Casco Bay Group and 1) the Vassalboro Formation north of Saco, and 2) the Berwick Formation in the Saco-Old Orchard Beach area is interpreted to be a folded premetamorphic fault (Hussey and Newberg, 1978; Pankiwskyj, 1970; Osberg, 1980; Newberg, 1981a, and Gates et al., 1984). The basis for this interpretation, as opposed to a simple sedimentary contact is quite speculative, resting on the disparity in ages inferred for each sequence. The Vassalboro Formation of early Silurian to possibly latest Ordovician age is juxtaposed against the Precambrian to early Ordovician age Cushing Formation of the Casco Bay Group. The contact is folded congruently with F_2 folds of both Casco Bay and Central Maine terranes. Metamorphic isograds, however, are not offset by this fault.

Similarly the contact between the Vassalboro and Rindgemere Formations is an inferred folded fault. On the basis of the presently held correlation of the Lower Member of the Rindgemere with the Sangerville Formation of the Central Maine Sequence, the Rindgemere should lie stratigraphically above the Windham Formation (equivalent to the Waterville), and thus cannot be in stratigraphic contact with the Vassalboro Formation. No alternative correlations of involved units are envisioned that could allow a stratigraphic contact between the two formations. Like the Casco Bay boundary fault, this fault has been folded congruently with F_2 folds of the two sequences.

The nature of the Bucksport-Cape Elizabeth contact in the Boothbay Harbor area is equally uncertain. At all of the several localities where it is exposed it appears conformable, but the two formations are not interbedded. A folded premetamorphic fault contact is required if the correlation of the Bucksport with the Vassalboro is valid for the same reasons as discussed above for the Casco Bay Group/Vassalboro-Berwick contact. If on the other hand the Bucksport of the Boothbay Harbor area (and perhaps a different stratigraphic unit than the Bucksport of the Bucksport area) is a facies of the upper part of the Cushing (the Sebascodegan Member) as discussed in an earlier section of this study, the contact would be stratigraphic. More certainty about regional correlations must be available before this question can be answered. The contact is folded by F_2 upright folds of the Casco Bay Group.

Based on very similar settings and correlations of the Massabesic Gneiss with parts of the Casco Bay Group, the Massabesic Gneiss may be allochthonous, essentially a klippe as proposed for the Casco Bay Group, and may occupy an F_2 synclinorium, not an anticlinorium.

Post-Metamorphic Faults

A series of post-metamorphic faults have been mapped through the Bath-Brunswick area south into New Hampshire (Hussey, 1971a, b; 1981; Bodine, 1965). Hussey (1981) correlates these faults collectively with the Norumbega Fault Zone of Stewart and Wones (1974) to which some of the faults have been traced (Hatheway, 1969; Newberg, 1981; Pankiwskyj, 1978; and Bickel, 1976). Included in this zone are the Nonesuch River, Flying Point, South Portland, Cape Elizabeth, and Phippsburg faults and an unnamed inferred fault just east of Macworth Island in Casco Bay.

Nonesuch River Fault. The Nonesuch River Fault is the northwestern most of the Faults of the Norumbega Fault Zone in the study area. It has been traced southwestard into New Hampshire (Hussey and Newberg, 1978) where it joins the Campbell Hill Fault of Lyons, et al. (1982). The Nonesuch River Fault has been traced to the northeast only as far as Yarmouth but it may possibly extend to the northeast to join the Pleasant Pond Fault of Newberg (1981a) north of the map area. Evidence for the Nonesuch River Fault includes:

1) juxtaposition of the Vassalboro and Cape Elizabeth Formations;

2) a topographic lineament formed by the northeast-trending stretch of Nonesuch River, the Presumpscot River, and the northeast-southwest course of the Saco River within the outcrop belt of the Saco Pluton;

3) truncation of metmorphic isograds in the Cape Elizabeth Formation, resulting in the juxtaposition of staurolite-grade Vassalboro against chlorite to garnet grade Cape Elizabeth; and

4) contortion of schistosity and the presence of white bull quartz and drusy quartz in the Cape Elizabeth Formation in the channel of the Nonesuch River south of Gorham (Hussey, 1981).

Hussey and Newberg (1978) suggest significant right-lateral strike-slip movement, possibly a few 10's of kilometers but not much more and certainly not of the order of 1500 km suggested for the Norumbega Fault system as a whole by Kent and Opdyke (1979). The possibility of left lateral movement cannot be ruled out if left lateral movement inferred for Flying Point Fault was assumed along the Nonesuch River Fault. Whatever the direction, strike slip movement is essentially locked by the Lyman and Saco Plutons, indicating that such movement was pre-Mississippian. Possible post plutonic reactivation of the Fault is suggested by the lineament in the Saco Pluton.

Flying Point Fault. The Flying Point Fault is traced from its inferred junction with the Nonesuch River Fault (south of Gorham) through Brunswick northeastward to the Richmond area just north of the map area. It may extend further to the northeast. In the Portland area this fault juxtaposes non-migmatized upper Greenschist Facies Macworth Formation on the southeast against pegmatite-injected, migmatized upper Amphibolite Facies Cushing and Vassalboro Formations on the northwest. Rocks of the the Casco Bay Group of comparable grade of metamorphism and migmatization southeast of the fault are encountered only northeast of Merrymeeting Bay between Bowdoinham and Woolwich, suggesting a possible 50 to 60 km of left-lateral strike-slipmovement, assuming net movement is stricktly horizontal. The actual movement may be considerably less if 1) net movement includes a significant component of dip slip, and 2) metamorphic isograd surfaces and migmatization front are gently dipping. Splays related to the Flying Point Fault can be seen in shoreline exposures at Johns Point on Flying Point, Freeport. Here rocks of the Cushing have been brecciated, and the foliation contorted and cut by numerous slickensided surfaces. Slickensides are generally steep, indicating that the latest movement was nearly dip slip. Localities where the position of this fault is closely determined (within 25 m) include Sturdivant Island, Cumberland; Bartlett Point, Falmouth (Bodine, 1965); and the small cove separating Flying Point from the Freeport mainland.

South Portland Fault. The South Portland Fault is indicated primarily by the omission of units of the Casco Bay Group in the South Portland-Great Chebeague Island area. The amount of slip probably does not exceed a few hundred meters. This gravity faulting cannot be dated, but speculatively is correlated with Late Triassic rifting in other parts of the northern Appalachians, and with the emplacement of most of the basic dikes of the coastal dike swarm.

Cape Elizabeth Fault. The Cape Elizabeth Fault has been traced by Hussey (1971a, b) and Newberg (1981a) from the Old Orchard Beach area to and beyond Dresden Mills just north of the study area. Pankiwskyj (1978) traces this fault to the northeast into the Norumbega Fault of Stewart and Wones (1974) in the Bangor area. The Cape Elizabeth Fault is well exposed in a 1 km wide zone along the shoreline in the Ram Island Farm area. Here, exposures of the Cape Elizabeth Formation show numerous variably-oriented high angle faults locally filled with breccia or gouge. The zone includes a west-dipping low angle thrust of unknown but potentially significant throw. This thrust fault may not be related to the principal movement of the Cape Elizabeth Fault. In the Ram Island Farm area, the principle break of the Fault is occupied by a 5 to 10 m wide vein of milky quartz traceable for approximately 2 km to the northeast along which different units of the Cushing Formation are juxtaposed against the Cape Elizabeth Formation. In the area of Harpswell Neck, Harpswell, the offset of the Cape Elizabeth-Cushing contact and the silimanite/andalusite isograd suggest possible left lateral strike slip movement of 4 to 5 km but this may be much less if there was a major component of dip slip motion, and if contacts and isograd surfaces are gently inclined.

Phippsburg Fault. The Phippsburg fault follows a marked topographic lineament from Small Point to Phippsburg Village (Hussey, work in progress). Although net movement on the fault must be very minor, this may be a significant break. The April 1979 earthquake epicenter lies within a few hundred meters of the extension of the topographic lineament in the Woolwich area.. In addition, exposures of the Cape Elizabeth Formation along State Highway 127 at the north end of Arrowsic Island show extensive slickensiding adjacent to where the lineament crosses the highway (J. R. Rand, pers. comm.)

Portsmouth Fault. The Portsmouth Fault which forms the Kittery-Rye contact on Gerrish Island, Kittery, is marked by a 25-30 m wide zone of ultramylonite with thin pseudotachylite veins interpreted to indicate thrusting of the Rye Formation over the Kittery (or possibly strike slip faulting) under deep-seated ductile deformation conditions (Hussey, 1980). A second ultramylonite within the Rye Formation 1 km south of the contact may represent another deep-seated ductile fault juxtaposing migmatized and non-migmatized blastomylonites of the Rye. Carrigan (1984) has mapped the continuation of this southern mylonite onto New Castle Island, N. H., where he refers to it as the Great Common Fault Zone.

Renewed faulting at a later time when the rocks had been brought into the brittle deformation field by uplift and erosion is suggested by the marked topographic lineament crossing the Island 50-100 m north of the Rye-Kittery ultramylonite contact zone.

Miscellaneous Faults

An unnamed fault is inferred to form the eastern contact of the Macworth Formation on the basis that the Casco Bay Group metapelites to the east are at a higher metamorphic grade than the Macworth rocks and that the Macworth contact truncates regional metamorphic isograds of these metapelites.

The writer has mapped a fault extending from Lebanon to the edge of the Rochester Pluton. This offsets the Towow-Upper Rindgemere, Upper Rindgemere-Lower Rindgemere, Lower Rindgemere-Gonic and Gonic-Berwick contacts, but is locked by the Rochester pluton. This fault continues on trend south of the Rochester Pluton to the vicinity of Wheelwright Pond in Lee, New Hampshre where it is marked in places by minor silicification and closely spaced shear surfaces.

The Flint Hill Fault of Freedman (1950) extends from Barrington, New Hampshire, south to the Raymond area. It is marked by silicified zones and retrograde metamorphism, but no observed or mappable offset. Silicified zones marking this fault are seen in the Rochester Pluton and the metasediments between Raymond and Nottingham, southeast of the Pluton.

Many minor faults, some too limited to show on Plate 2, affect the rocks of the the Casco Bay Group. Some of these are marked by silicified zones, gouge, and breccia in which no observable offset can be demonstrated. Many minor northwest trending faults, particularly in the Harpswell-Portland area, are parallel to left lateral kinks (F_6) and may represent situations where deformation has exceeded the limits of kinking and passes on into minor left lateral strike-slip motion. Movement on these faults seldom exceeds 10 or 20 m. Similarly, several faults, with offsets of a few tens of meters at most, have been mapped in the Boothbay-Bristol region (Hussey, 1984b).

Plate II shows locations of earthquake epicenters during the years 1776 to 1979 (after Chiburis, 1981) and the post metamorphic faults discussed above. The total distribution of epicenters shows no preferred concentration relative to known faults. An exception to this may be the Portland area where several epicenters appear to lie close to the intersection of the Nonesuch River and Flying Point Faults, and the Bath area where the April 1979 epicenter lies close to the Phippsburg Fault. This suggests the possibility that some of the faults of the Norumbega Fault system may be intermittently active.

METAMORPHISM

The stratified rocks of the study area have been metamorphosed in a low-pressure intermediate (Buchan-type) facies series from low Greenschist Facies to upper Amphibolite Facies. Pelitic rocks are characterized at intermediate grade by the presence of andalusite, cordierite, and staurolite, the latter overlapping the lower temperature part of the sillimanite stability field. The presence of kyanite in the Gorham-Gray area suggest a transition there to a higher pressure Barrovian-type metamorphism.

Pelitic rocks of the Small Point area, now at andalusite and sillimanite grades of metamorphism, preserve 2 to 4 cm long pseudomorphs of muscovite after chiastolite, suggesting an earlier intermediate grade of metamorphism.

Retrograde metamorphism has variably affected the entire study area and is expressed in the partial to locally complete chloritization of biotite, and, in the Shapleigh Group, complete pseudomorphing of chiastolite by muscovite and partial chloritization of garnet. Chloritization is particularly strong in the quartzo-feldspathic rocks of the Cushing Formation adjacent to the Flying Point Fault and the Cape Elizabeth Fault in the Brunswick-Topsham area.

TIME OF DEFORMATION AND METAMORPHISM

Because the low-angle premetamorphic faults are locked by undeformed Mississippian age plutons (Sebago, Lyman, and Saco), movement and folding of these faults must predate the Mississippian. However, since these faults juxtapose sequences of stratigraphic units of Silurian and Devonian age against older rocks, such movement and folding cannot be older than Devonian, and must be a result of the Acadian orogeny. Similarly, since F_1 recumbent folds and F_2 upright folds of the Central Maine Sequence and the Shapleigh Group affect rocks of Silurian and Devonian age, but are truncated by the Sebago and Lyman Plutons, these deformations are also a result of the Acadian Orogeny. F_3 folds of the Cental Maine sequence, locally developed around the Lyman Pluton, are of Mississippian age and related to the intrusion of that pluton. Regional metamorphism of the Central Maine Sequence and the Shapleigh Group must also be related to the Acadian orogeny: zones of medium to high grade metamorphism are overprinted by, therefore are older than, the thermal aureole of Mississippian age around the Lyman Pluton. Folds of the premetamorphic fault bounding the Casco Bay Group are interpreted to be congruent with F_2 folds of the Casco Bay Group and Bucksport Formation (Hussey, 1984a; Gates, et al., 1984); consequently F_2 folds must also be due to the Acadian Orogeny.

A thermal event associated with F_2 development, possibly the principal prograde metamorphism of the Casco Bay Group, is clearly indicated by the recrystallization of both biotite and muscovite from parallelism to axial planes of F_1 to parallelism to those of F_2. If F_2 folds were produced during the Acadian Orogeny, this metamorphism must also be an Acadian feature. The radiometric age of 480-490 Ma for the Cushing and Cape Elizabeth Formations, interpreted by Lyons et al. (1982) as a metamorphic age, may represent only a partial resetting of the Rb/Sr system of rocks of late Precambrian age by an early Devonian metamorphism associated with the Acadian Orogeny. Age of the earlier metamorphism that produced the pseudoandalusites in schists at Small Point, and of the recumbent folds, F_1, of the Casco Bay Group are not known but might be as old as Late Precambrian.

The time of deformation and metamorphism of the Merrimack Group is particularly difficult to assess because of the earlier expressed uncertainties as to correlation and age of the Group. A minimum age of early Devonian is suggested by the fact that F_2 structures of the Kittery Formation are truncated by the post-orogenic phases of the Webhannet Pluton dated as early Devonian by Gaudette et al. (1982) Gaudette et al. (1984) argue for an older age on the basis of the 473 Ma Rb/Sr age of the Exeter Pluton and 450 Ma for the Newburyport Pluton. Lyons et al. (1982) argue for an age older than Acadian on the basis of proximity of unmetamorphosed paleontologically-dated Newbury Volcanics to regionally metamorphosed Merrimack Group in northeastern Massachusetts. However, the Newbury Volcanics are not in contact with the Merrimack Group, and they are fault bounded raising the possibility that they have been moved to their present position by considerable strike-slip movement.

The great similarity in sequence of rocks of the Merrimack Group and the Central Maine Sequence still argues strongly for a correlation of these sequences. If these rocks are of Silurian age, the deformation and metamorphism would be related to the Acadian Orogeny. That F_2 deformation, at least, is of Acadian age is further suggested by the parallelism of macroscopic F_2 folds of the Merrimack Group to those of other sequences more clearly of Acadian age. The lithic similarities are striking enough by themselves as to suggest that existing radiometric dates be reexamined very critically.

Evidence for late Carboniferous Alleghanian deformation and metamorphism is lacking. The postmetamorphic Nonesuch River Fault underwent principal movement prior to the emplacement of the Lyman, Rochester, and Saco Plutons, whose contacts with the Berwick Formation are not offset where the Fault trends into them. Reactivation of the Fault after emplacement of the Lyman and Saco Plutons is suggested by topgraphic lineaments within both plutons (Hussey and Newberg, 1978). This later movement was not of sufficient magnitude to notably offset the pluton contracts. Similarly the postmetamorphic Cape Elizabeth Fault appears to align itself with a topographic lineament in the Biddeford Granite, but again, the Biddeford/ Berwick contact is not offset; thus the major strike slip motion inferred for this fault must predate the Mississippian. Furthermore since both this and the Nonesuch River Faults offset metamorphic isograds, metamorphism of all the metasedimentary sequences was accomplished prior to major plutonism. The topographic lineament in the Biddford Pluton may represent normal faulting associated with the development of the South Portland Fault which is downdropped on its northwest side. The lineament through the Lyman and Saco plutons may similarly represent reactivation of the Nonesuch River Fault by normal faulting. Such normal faulting is then of post Mississippian age and may be associated with Triassic rifting in the northern Appalachians.

REFERENCES

Barosh, P., and Pease, M. H., Jr., 1981, Correlation of the Oakdale and Paxton Formations with their equivalents from Eastern Connecticut to southern Maine: NEGSA, Abstracts with Programs, v. 13, n. 3, p. 122.

Bell, K. G., and Alvord, D. C., 1976, Pre-Silurian stratigraphy of northeastern Massachusetts: Geol. Soc. Amer. Mem. 148, p. 179-216.

Besancon, J. R., Gaudette, H. E., and Naylor, R. S., 1977, Age of the Massabesic Gneiss, southeastern New Hampshire: NEGSA Abstracts with Programs, v. 9, n. 3, p. 242.

Bickel, C. E., 1976, Stratigraphy of the Belfast quadrangle, Maine: Geol. Soc. Amer. Mem. 148, p. 97-128.

Billings, M. P., 1956, The Geology of New Hamphire, Pt. 2: Bedrock Geology: Concord, N. H., New Hampshire State Planning and Development Commission, 203 p.

Bodine, M. W., Jr., 1965, Stratigraphy and metamorphsm in southwestern Casco Bay, Maine: in Guidebook, 57th New England Geological Conference, Brunswick, Maine, p. 57-72.

Boone, G. McG., 1973, Metamorphic stratigraphy, petrology, and structural geology of the Little Bigelow Mountaine map area, western Maine: Maine Geol. Surv., Bull. 24, 136 p.

Bothner, W. A., 1974, Gravity study of the Exeter Pluton, southeastern New Hampshire: Geol. Soc. Amer. Bull., v. 85, p. 51-566.

Bothner, W. A., Boudette, E. L., Fagan, T. J., Gaudette, H. E., Laird, J., and Olszewski, W. J., 1984, Geologic Framework of the Massabesic Anticlinorium and the Merrimack Trough, southeastern New Hampshire: in Hanson, L. S., ed., Geology of the coastal Lowlands, Boston, Mass. to Kennebunk, Maine: New England Intercollegiate Geological Conference, 1984, Trip B5, p. 186-206.

Boucot, A. J., Brookins, D., Forbes, W. and Guidotti, C. V., 1972, Staurolite zone Caradoc (Middle-Late Ordovician) age, Old World province brachiopods from Penobscot Bay, Maine: Geol. Soc. Amer. Bull., v. 83, p. 1953-1960.

Brookins, D. G., and Hussey, A. M. II, 1978, Rb-Sr ages for the Casco Bay Group and other rocks from the Portland-Orrs Island area, Maine: Geol. Soc. Amer. Abstracts with Programs, v. 10, n. 2, p. 34.

Chiburis, E. F., 1981, Seismicity, recurrence rates, and regionalization of the northeastern United States and adjacent southeastern Canada: Dept. Geology and Geophysics, Weston Observatory, Boston College, 76 p.

Christopher, P. A., 1969, Fission track ages of younger intrusions in southern Maine: Geol. Soc. Amer. Bull., v. 80, p. 1809-1813.

Dallmeyer, R. D., and Vanbreeman, O., 1981, Rb-Sr Whole rock ages of the Togus, Hallowell, and Three Mile Ponds Plutons: Contr. Min. and Petr., v. 78, p. 61-73.

Elders, W. A., 1969, Zoned alkali feldspars from the Lincoln Sill syenite, Maine: Geol. Soc. Amer., Abstracts with Programs, Pt. 7, p. 271-273.

Eusden, J. D., 1984, The bedrock geology of part of the Alton, New Hampshire and Berwick, Maine 15' quadrangles; M.S. thesis, Univ., New Hampshire, 114 p.

Eusden, J. D., Bothner, W. A., Hussey, A. M. II, and Laird, J., 1984, Silurian and Devonian rocks in the Alton and Berwick quadrangles, New Hampshire and Maine: in Hanson, L. S., ed, Geology of the Coastal Lowlands, Boston, Mass. to Kennebunk Maine: New England Intercollegiate Geological Conference, 1984, Trip C5, p. 325-351.

Foland, K. A., and Faul, H., 1977, Ages of the White Mountain intrusives -- New Hampshire, Vermont, and Maine, USA: Amer. Jour. Sci., v. 277, p. 888-904.

Fowler-Billings, K., 1959, Geology of the Isles of Shoals, New Hampshire and Maine: Concord, N. H., New Hampshire State Planning and Development Commission, 51 p.

Freedman, J., 1950, Stratigraphy and structure of the Mt. Pawtuckaway quadrangle, southeastern New Hampshire: Geol. Soc. Amer. Bull., v. 61, p. 449-492.

Gates, O., 1961, Geology of the Cutler and Moose River quadrangles, Washington County, Maine: Quad Map Series 1, Maine Geol. Surv., 67 p.

______, Hussey, A. M. II, and Osberg, P. H., 1984, Acadian thrust plates in coastal Maine: Geol. Soc. Amer., Abstracts with Programs, 1984, v. 16, n. 1, p. 17.

Gaudette, H. E., Kovach, A., and Hussey, A. M. II, 1982, Ages of some intrusive rocks of southwestern Maine, U.S.A.: Canadian Jour. Earth Sci., v. 19, p. 1350-1357.

______, Bothner, W. A., Laird, J., Olszewski, W. J., and Cheetam, M. M., 1984, Late Precambrian/Early Paleozoic deformation and metamorphism in southeastern New Hampshire -- Confirmation of an exotic terrane: Geol. Soc. Am., Abstract with Programs, 1984, p. 516.

Gilman, R. A., 1965, Geology of the Kezar Falls-Newfield area Maine: in Guidebook, 57th New England Intercollegiate Geological Conference, Brunswick, Maine, p. 85-93.

______, 1970, Structural and stratigraphic studies in the Sawyer Mountain area, York County, Maine: Maine Geol. Surv., Bull. 23, Shorter Contributions to Maine Geology, p. 53-57.

______, 1972, Small Mesozoic plutons of the Newfield-Kezar Falls quadrangles: Open-File Report, Maine Geol. Surv., Augusta, Maine.

______, 1977, Geologic Map of the Kezar Falls 15' quadrangle: Maine Geol. Surv., Geol. Map Series GM-4.

Guidotti, C. V., 1979, Preliminary report on the bedrock geology of the Tenants Harbor 7 1/2' quadrangle and a portion of the Friendship 7 1/2' quadrangle Maine: Maine Geol. Surv., Open-File Report 79-16, 12 p.

Haff, J. C., 1939, Multiple dikes of Cape Neddick: Geol. Soc. Amer. Bull., v. 50, p. 835-963.

______, 1941, Contaminated complex dike at Cape Neddick, Maine: Jour. Geol., v. 49, p. 835-963.

______, 1943, Alkaline vitrophyre dike, Cape Neddick, Maine: Amer. Mineralogist, v. 28, p. 426-436.

Hatheway, R. B., 1969, Geology of the Wiscasset quadrangle, Maine: Unpub. PhD dissert., Cornell Univ., Ithaca, N. Y., 166 p.

______, 1964, Origin of the Saco pluton, Saco, Maine: Unpub. MS thesis, Univ. Missouri, 112 p.

Hitchcock, C. H., 1861, General report upon the geology of Maine: Preliminary Report Nat. Hist. and Geol.: in Maine Board of Agriculture, 6th Annual Report, p. 146-328.

______, 1862, Second annual report on the geology of Maine: in Maine Board of Agriculture 7th Annual Report.

Hoefs, J., 1967, A Rb-Sr investigation in the southern York County area, Maine; variations in isotopic abundances of Sr, Ca, and argon and related topics: M.I.T., Cambridge, Mass., 15th Annual Report p. 127-129.

Hussey, A. M. II, 1962, The geology of southern York County, Maine: Maine Geol. Surv., Spec. Studies Series, N. 4, 67 p.

______, 1965, Geology of the Orrs Island 7 1/2' quadrangle: in 57th New England Intercollegiate Conference Guidebook, Bowdoin College, p. 4-23.

______, 1968, Stratigraphy and structure of southwestern Maine: in Zen, E-an, et al., eds., Studies of Appalachian Geology: Northern and Maritime: Interscience Publishers, New York, p. 291-301.

______, 1971a, Geologic Map of the Portland 15' quadrangle, Maine: Maine Geol. Surv., Geol. Map Series GM-1.

______, 1971b, Geologic Map and cross sections of the Orrs Island 7 1/2' quadrangle and adjacent area, Maine: Maine Geol. Surv., Geol. Map Series GM-2.

______, 1972, Reconnaissance bedrock geology of the Friendship 7 1/2' quadrangle, Maine: Maine Geol. Surv., Open-File Map 71-9.

______, 1978, Bedrock geology of the Casco Bay Group, Portland, Maine: Guidebook, field trip 3, Geol. Soc. Maine.

______, 1980, The Rye Formation of Gerrish Island, Kittery Maine: a reinterpretation: The Maine Geologist (Newsletter of the Geological Society of Maine), v. 7, n. 2, p. 2-3.

______, 1981, Bedrock Geology of the Lower Androscoggin Valley-Casco Bay Area, Maine: in Maine Geol. Surv., New England Seismotectonic Study Activities in Maine during Fiscal Year 1981, p. 31-56.

______, 1982a, Stratigraphic column for southwestern Maine: Amer. Assoc. Petr. Geol. COSUNA Project, in preparation.

______, 1982b, Geology of the Two Lights and Crescent Beach State Parks area, Cape Elizabeth, Maine: Maine Geol. Surv., Bull. 26, 34 p.

______, 1984a, Age and correlation of stratigraphic units of southwestern Maine: a reconsideration: Geol. Soc. Amer., Abstracts with Programs, 1984, v. 16, n. 1, p. 26.

______, 1984b, Bedrock geology of the Boothbay 15' quadrangle, Maine: Guidebook, Field trip 14, Geological Society of Maine, 11 p.

______, and Newberg, D. W., 1978, Major Faulting in the Merrimack Synclinorium between Hollis, New Hampshire, and Biddeford, Maine: Geol. Soc. Amer. Abstracts with Programs, v. 10, n. 2, p. 48.

______, and Pankiwskyj, K. A., 1976, Preliminary geologic map of southwestern Maine: Maine Geol. Surv., Open-File Map 76-1.

______, Rickerich, S. F., and Bothner, W. A., 1984, Sedimentology and multiple deformation of the Kittery Formation, southwestern Maine, and New Hampshire: in, Hanson, L. S., ed., Geology of the Coastal Lowlands, Boston, Mass. to Kennebunk, Maine: New England Intercollegiate Geological Conference, 1984, Trip A4, p. 47-60.

Jackson, C. T., 1837, First Report of the Geology of the State of Maine: Augusta, 128 p.

______, 1838, Second Report on the Geology of the State of Maine: Augusta, 168 p.

______, 1839, Third Annual Report on the Geology of the State of Maine: Augusta, 276 p.

Katz, F. J., 1917, Stratigraphy in southwestern Maine and southeastern New Hampshire: U.S. Geol. Surv. Prof. Paper 108, p. 165-177.

Kelley, F. J. 1914, Notes on some igneous rocks at Ogunquit, Maine, and Pigeon Cove, Mass.: Phila. Acad. Nat. Sci. Proc., v. 66, p. 3-8.

______, 1924, Additional notes on igneous rocks of Ogunquit, Maine: Phila. Acad. Nat. Sci. Proc., v. 75, p. 105-109.

Kelley, W. J., Olszewski, W. J., and Gaudette, H. E., 1980, The Massabesic Gneiss revisited: A Rb/Sr whole rock study of the Massabesic orthogneiss, southern New Hampshire: Geol. Soc. Amer. Abstracts with Programs, v. 12, n. 2, p. 45.

Kemp, J. F., 1890, On the dikes near Kennebunkport, Maine: Amer. Geol., v. 5, p. 129-140.

Kent, D. V., and Opdyke, N. D., 1978, Paleomagnetism of the Devonian Catskill Redbeds: evidence of motion of the coastal New England-Canadian maritime region relative to cratonic North America: Jour. Geophys. Res., v. 83, p. 4441-4450.

Kirk, A. R., 1971, Petrology, structural geology, and metamorphism of the Boothbay Harbor area,, Maine: Unpub. MS thesis, Univ. of New York at Buffalo, 108p.

Lord, E. C. E., 1898, on the dikes in the vicinity of Portland, Maine: Amer. Geol. v. 22, p. 335-346.

Lyons, J. B., Boudette, E. L., and Aleinikoff, J. N., 1982, The Avalonian and Gander zones in central eastern New England: Can. Jour. Earth Sci. Spec. Paper 24, p. 43-66.

McHone, J. G., and Trygstad, J. C., 1982, Mesozoic mafic dikes of southern Maine: Geol. Soc. Maine, Bull. 2, Shorther Contributions to the geology of Maine, p. 16-32.

Moench, R. E., and Hildreth, C. T., 1976, Geologic map of the Rumford quadrangle, Oxford and Franklin Counties, Maine: U.S. Geol. Surv. Geol., Quad. Map GQ-1272.

Newberg, D. W., 1976, Geologic map of the Friendship 7 1/2' quadrangle: Maine Geol. Surv., Progress Report, 5 p.

______, 1981a, Bedrock geology and structure of the Gardiner 15' quadrangle, southwestern Maine: New England Seismotectonic Study Activities, in Maine during Fiscal Year 1981: Maine Geol. Surv., p. 57-66.

______, 1981b, Bedrock geology and structure of parts of the Vassalboro and Wiscasset 15' quadrangles, Maine: New England Seismotectonic Study Activites in Maine during Fiscal Year 1981; Maine Geol. Surv., p. 67-69.

Novotny, R. E., 1969, Geology of the seacoast region, New Hampshire: Concord, N. H., New Hampshire State Planning and Development Commission, 41p.

Ogilvie, I., 1907, A contribution to the geology of southern Maine: N. Y. Acad. Sci. Annals, v. 17, Pt. 2, p. 519-558.

Osberg, P. H., 1968, Stratigraphy, structural geology, and metamorphism in the Waterville-Vassalboro area, Maine: Maine Geol. Surv., Bull. 20, 64 p.

______, 1974, Forward, in 66th New England Intercollegiate Geological Conference guidebook, Orono, Maine, p. iii-xii.

______, 1979, Geologic relations in south-central Maine in Skehan, J. W. and Osberg, P. H., ed., The Caledonides in the U.S.A. Geological excursions in the northeast Appalachians: Weston Observatory, p. 37-62.

______, 1980, Stratigraphic and structural relations in the turbidite sequence of south central Maine: in Guidebook, 72nd New England Geological Conference Guidebook, Presque Isle, Maine, p. 278-296.

Osberg, P. H., and Guidotti, C. V., 1974, The Geology of the Camden-Rockland aera, in Guidebook, 66th New England Intercollegiate Geological Conference; Orono, Maine, p. 48-60.

Palache, C. A., 1934, A topaz deposit in Topsham, Maine: Amer. Jour. Sci, 5th Ser., v. 27, p. 37-48.

Pankiwskyj, K. A., 1978, Bedrock Geology of the Coopers Mills-Liberty, Maine, area: Geol. Soc. Maine, Guidebook for Field Trip 3.

______, 1979, Geologic Maps of the Kingfield and Anson 15' quadrangles. Maine: Maine Geol. Surv., Map Series GM-7.

Pendexter, C. A., 1949, A study of the metamorphic formations of southwestern Maine: unpub. MS thesis, Washington Univ., St. Louis, MO, 82 p.

Perkins, E. H., and Smith, E. S. C., 1925, Contributions to the geology of Maine, NO. 1: a Geological Section from the Kennebec River to Penobscot Bay: Amer. Jour. Sci, v. 209, p. 204-228.

Powers, S., 1915, On the origin of inclusions in dikes: Jour. Geol., v. 23, p. 1-10, 166-182.

Shride, A. F., 1976, Stratigraphy and correlation of the Newbury volcanic complex, northeastern Massachusetts: Geol. Soc. Amer. Mem. 148, p. 147-177.

Smith, P. V., and Barosh, P. J., 1981, Structural geology of the Nashua Trough, southern New Hampshire: Geol. Soc. Amer., Abstracts with Programs, v. 13, n. 3, p. 178.

Stewart, D. B., and Wones, D. R., 1974, Bedrock geology of the northern Penobscot Bay area: in Guidebook, 66th New England Intercollegiate Geological Conference, Orono, Maine, p. 223-239.

Stewart, G. W., 1961, Geology of the Alton quadrangle: New Hampshire Planning and Development Commission, Concord, N.H., 33 p.

Swanson, M. T., 1982, The structures and tectonics of Mesozoic dike swarms in eastern New England: PhD dissert., SUNY Albany, 278 p.

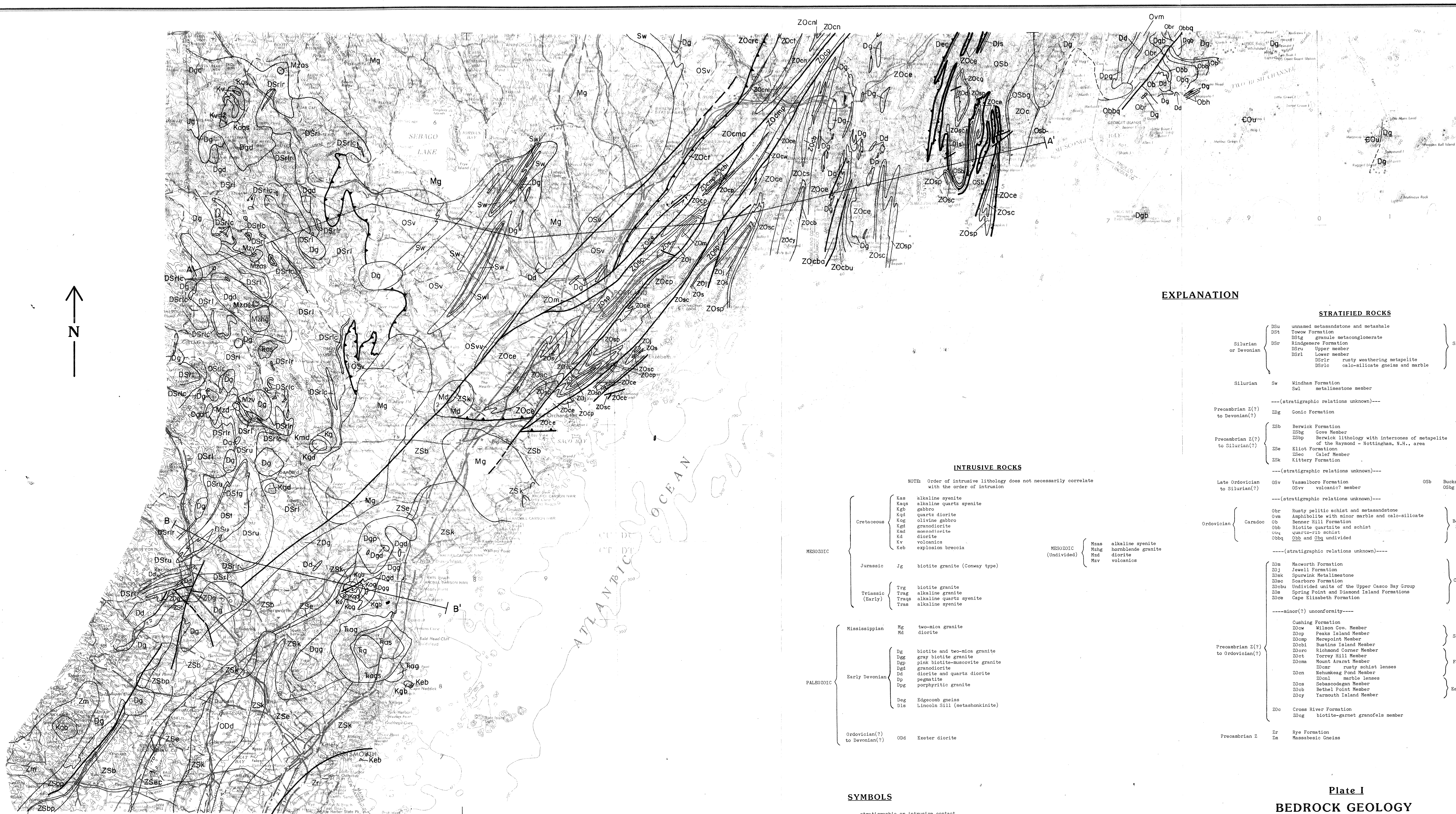
Trefethen, J. M., 1937, The Lincoln Sill: Jour. Geol., v. 45, p. 353-380.

Wandke, A., Intrusive rocks of the Portsmouth basin, Maine and New Hampshire: Amer. Jour. Sci., 5th Ser., v. 4, p. 139-158.

Wilson, J. R., 1969, The Geology of the Ossippee Lake quadrangle, New Hampshire: New Hampshire Department of Resources and Economic Development, Concord, N. H., Bull. 3, 116 p.

Wing, L. A., 1958, An aeromagmetic and geologic reconnaissance survey of portions of Hancock and Penobscot Counties, Maine: Maine Geol. Surv., GP and G Survey #1.

Woodard, H. H., 1957, Diffusion of chemical elements in some naturally occurring silicate inclusions: Jour. Geol., v. 65, p. 61-84.



EXPLANATION

STRATIFIED ROCKS

Silurian or Devonian	DSu	unnamed metasandstone and metashale	Shapleigh Group
	DSt	Towow Formation	
	DStg	granule metaconglomerate	
	DSr	Rindgemere Formation	
	DSru	Upper member	
	DSrl	Lower member	
	DSrlr	rusty weathering metapelite	
	DSrlc	calc-silicate gneiss and marble	
Silurian	Sw	Windham Formation	
	Swl	metalimestone member	

---(stratigraphic relations unknown)---

Precambrian Z(?) to Devonian(?)	ZDg	Gonic Formation	
Precambrian Z(?) to Silurian(?)	ZSb	Berwick Formation	Merrimack Group
	ZSbg	Gove Member	
	ZSbp	Berwick lithology with interzones of metapelite of the Raymond - Nottingham, N.H., area	
	ZSe	Eliot Formationn	
	ZSec	Calef Member	
	ZSk	Kittery Formation	

---(stratigraphic relations unknown)---

Late Ordovician to Silurian(?)	OSv	Vassalboro Formation	OSb	Bucksport Formation
	OSvv	volcanic? member	OSbg	calc-silicate gneiss

---(stratigraphic relations unknown)---

Ordovician	Caradoc	Obr	Rusty pelitic schist and metasandstone	Benner Hill Sequence
		Ovm	Amphibolite with minor marble and calc-silicate	
		Ob	Benner Hill Formation	
		Obb	Biotite quartzite and schist	
		Obq	Quartz-rib schist	
		Obbq	Obb and Obq undivided	

----(stratigraphic relations unknown)----

Precambrian Z(?) to Ordovician(?)	ZOm	Macworth Formation	Casco Bay Group
	ZOj	Jewell Formation	
	ZOsk	Spurwink Metalimestone	
	ZOsc	Scarboro Formation	
	ZOcbu	Undivided units of the Upper Casco Bay Group	
	ZOs	Spring Point and Diamond Island Formations	
	ZOce	Cape Elizabeth Formation	
		----minor(?) unconformity----	
		Cushing Formation	
	ZOcw	Wilson Cove Member	South Portland-Harpswell Belt
	ZOcp	Peaks Island Member	
	ZOcmp	Merepoint Member	
	ZOcbi	Bustins Island Member	
	ZOcrc	Richmond Corner Member	Falmouth-Brunswick Belt
	ZOct	Torrey Hill Member	
	ZOcma	Mount Ararat Member	
	ZOcmr	rusty schist lenses	
	ZOcn	Nehumkeag Pond Member	
	ZOcnl	marble lenses	
	ZOcs	Sebascodegan Member	East Harpswell-Merrymeeting Bay Belt
	ZOcb	Bethel Point Member	
	ZOcy	Yarmouth Island Member	
	ZOc	Cross River Formation	
	ZOcg	biotite-garnet granofels member	
Precambrian Z	Zr	Rye Formation	
	Zm	Massabesic Gneiss	

INTRUSIVE ROCKS

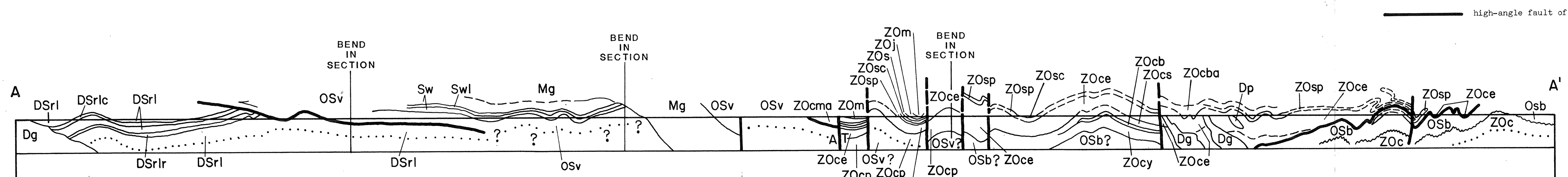
NOTE: Order of intrusive lithology does not necessarily correlate with the order of intrusion

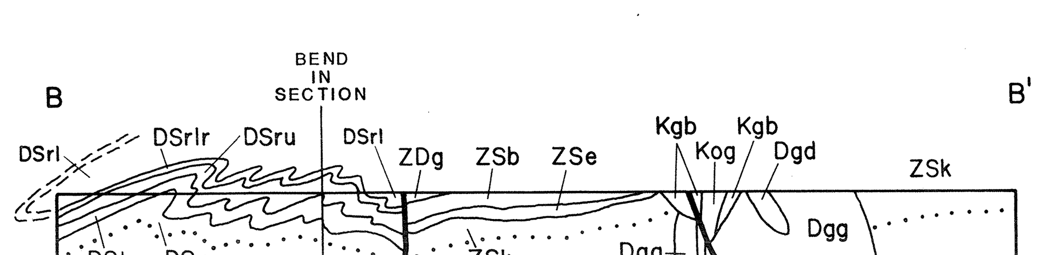
MESOZOIC	Cretaceous	Kas	alkaline syenite
		Kaqs	alkaline quartz syenite
		Kgb	gabbro
		Kqd	quartz diorite
		Kog	olivine gabbro
		Kgd	granodiorite
		Kmd	monzodiorite
		Kd	diorite
		Kv	volcanics
		Keb	explosion breccia
	Jurassic	Jg	biotite granite (Conway type)
	Triassic (Early)	Trg	biotite granite
		Trag	alkaline granite
		Traqs	alkaline quartz syenite
		Tras	alkaline syenite
PALEOZOIC	Mississippian	Mg	two-mica granite
		Md	diorite
	Early Devonian	Dg	biotite and two-mica granite
		Dgg	gray biotite granite
		Dgp	pink biotite-muscovite granite
		Dgd	granodiorite
		Dd	diorite and quartz diorite
		Dp	pegmatite
		Dpg	porphyritic granite
		Deg	Edgecomb gneiss
		Dls	Lincoln Sill (metashonkinite)
	Ordovician(?) to Devonian(?)	ODd	Exeter diorite

MESOZOIC (Undivided)	Mzas	alkaline syenite
	Mzhg	hornblende granite
	Mzd	diorite
	Mzv	volcanics

SYMBOLS

- stratigraphic or intrusive contact
- normal fault, D - downthrown; U - upthrown
- strike-slip fault
- thrust fault (teeth on upper plate)
- high-angle fault of uncertain character





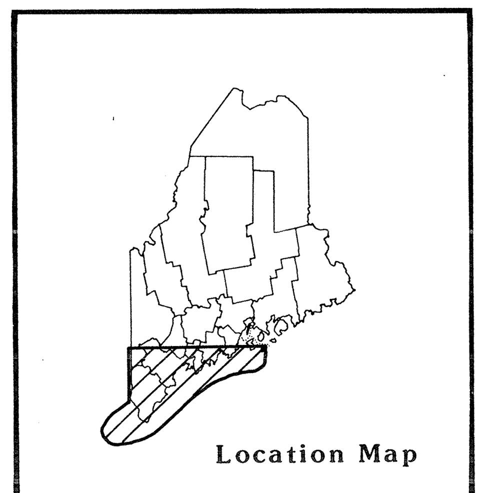

Location Map

Plate I

BEDROCK GEOLOGY OF THE BATH AND PORTLAND 2° MAP SHEETS, MAINE

by

ARTHUR M. HUSSEY II

Maine Geological Survey
DEPARTMENT OF CONSERVATION
Walter A. Anderson, State Geologist
1985

OPEN FILE NO. 85-87

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

5 0 5 10 15 Nautical Miles

LEGEND

Recumbent F_1 syncline

Upright to slightly overturned F_2 antiform

Upright to slightly overturned F_2 synform

Downward-facing overturned F_2 antiform (antiformal syncline)

Axial traces of folds of uncertain nature

Normal fault (D: downthrown, U: upthrown)

Strike slip fault showing relative direction of horizontal movement

Premetamorpnic folded thrust fault, teeth on upper plate

Fault of unknown character

Post-tectonic alkalic plutons (Ћ-K)

Post-tectonic gabbroic complexes and explosion breccias (K age)

Calc-alkaline plutons of D-M age: felsic

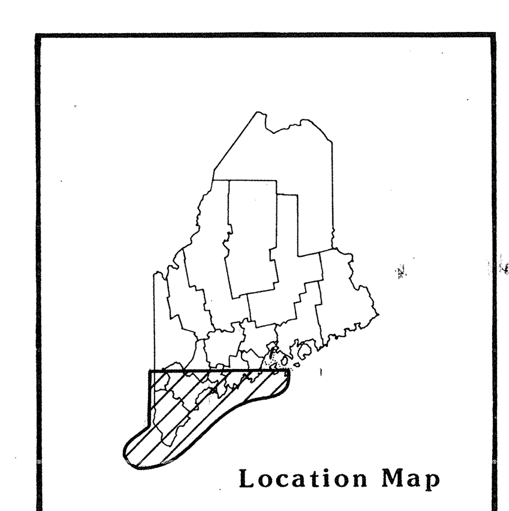
Calc-alkaline plutons of D-M age: mafic

Gneiss

Approximate location of historic earthquake epicenters:

● 1920 IV year and Mercalli intensity

● 1978 (4.0) year and Richter magnitude



Location Map

Plate II

GENERALIZED TECTONIC MAP OF THE

BATH AND PORTLAND 2° MAP SHEETS, MAINE

by

ARTHUR M. HUSSEY II

Maine Geological Survey
DEPARTMENT OF CONSERVATION
Walter A. Anderson, State Geologist

1985

OPEN FILE NO. 85-87

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

5 0 5 10 15 Nautical Miles